# Outfall Benthic Monitoring Report: 2017 Results

Massachusetts Water Resources Authority

Environmental Quality Department
Report 2018-05

**Citation:**

Nestler EC, Diaz RJ, Hecker B. 2018. Outfall benthic monitoring report: 2017 results. Boston: Massachusetts Water Resources Authority. Report 2018-05. 57 p., plus appendices.

# Outfall Benthic Monitoring Report: 2017 Results

**Submitted to**

**Massachusetts Water Resources Authority**
**Environmental Quality Department**
**100 First Avenue**
**Charlestown Navy Yard**
**Boston, MA 02129**
**(617) 242-6000**

**Prepared by**

**Eric C. Nestler[1]**
**Robert J. Diaz[2]**
**Barbara Hecker[3]**

**[1]Normandeau Associates, Inc.**
**25 Nashua Road**
**Bedford, NH 30110**

**[2]Diaz and Daughters**
**6198 Driftwood Lane**
**Ware Neck, VA 23178**

**[3]Hecker Environmental**
**26 Mullen Way**
**Falmouth, MA 02540**

**December 2018**
**Report No. 2018-05**

## EXECUTIVE SUMMARY


Benthic monitoring during 2017 included soft-bottom sampling for sediments, sediment contaminants, and infauna at 14 nearfield and farfield stations, sediment profile imaging (SPI) at 23 nearfield stations, and video surveillance at 23 hard bottom locations.

Sediment conditions were characterized based on spore counts of the anaerobic bacterium, *Clostridium perfringens*, analyses of sediment grain size composition and total organic carbon (TOC), and analyses of organic and inorganic chemical contaminants. Consistent with past observations during the post-diversion period, *C. perfringens* concentrations during 2017 were highest at sites closest to the discharge. Maciolek et al. (2007, 2008) documented this spatial pattern was statistically significant in previous years. The results for *C. perfringens*, therefore, provide evidence of settlement of solids from the effluent at sites in close proximity (within 2 km) to the outfall. Neither sediment grain size, TOC, nor contaminants have exhibited appreciable changes from the baseline period and this pattern continued in 2017. These results indicate the absence of influence of the wastewater discharge on sediment conditions, consistent with prior monitoring results (Nestler et al. 2017, Nestler et al. 2016, Maciolek et al. 2008).

Infaunal communities in Massachusetts Bay also continued to exhibit no evidence of impacts from the offshore outfall in 2017. Monitoring results have consistently suggested that deposition of particulate organic matter from the wastewater discharge is not occurring at levels that disturb or smother animals near the outfall. There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2017. Multivariate analyses indicated that patterns in the distribution of faunal assemblages reflect habitat types at the sampling stations. Infaunal data in 2017 continue to suggest that the macrobenthic communities at sampling stations near the outfall have not been adversely impacted by the wastewater discharge.

The 2017 SPI survey found no indication that the wastewater discharge has resulted in low levels of dissolved oxygen in nearfield sediments. The average thickness of the sediment oxic layer in 2017 was greater than during the baseline period, and among the highest reported during post-discharge years. These results support previous findings that organic loading and an associated decrease in oxygen levels have not been a problem at the nearfield benthic monitoring stations (Nestler et al. 2017, Maciolek et al. 2008). The outfall is located in an area dominated by hydrodynamic and physical factors, including tidal and storm currents, turbulence, and sediment transport (Butman et al. 2008). These physical factors, combined with the high quality of the effluent discharged into the Bay (Taylor 2010), are the principal reasons that benthic habitat quality has remained high in the nearfield area.

Hard-bottom benthic communities near the outfall have not changed substantially during the post-diversion period as compared to the baseline period. Some modest changes in hard-bottom communities (coralline algae and upright algae cover) have been observed; nonetheless, factors driving these changes are unclear. Since declines in upright algae started in the late 1990s, it is unlikely that the decrease was attributable to diversion of the outfall.

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# 1. INTRODUCTION

The Massachusetts Water Resources Authority (MWRA) has conducted long-term monitoring since 1992 in Massachusetts Bay and Cape Cod Bay to evaluate the potential effects of discharging secondary treated effluent 15 kilometers (km) offshore in Massachusetts Bay. Relocation of the outfall from Boston Harbor to Massachusetts Bay in September 2000 raised concerns about potential effects of the discharge on the offshore benthic (bottom) environment. These concerns focused on three issues: (1) eutrophication and related low levels of dissolved oxygen; (2) accumulation of toxic contaminants in depositional areas; and (3) smothering of animals by particulate matter.

Under its Ambient Monitoring Plan (MWRA 1991, 1997, 2001, 2004, 2010) the MWRA has collected extensive information over a nine-year baseline period (1992–2000) and a seventeen-year post-diversion period (2001–2017). These studies include surveys of sediments and soft-bottom communities using traditional grab sampling and sediment profile imaging (SPI) as well as surveys of hard-bottom communities using a remotely operated vehicle (ROV). Data collected by this program allow for a more complete understanding of the bay system and provide a basis to explain any changes in benthic conditions and to address the question of whether MWRA's discharge has contributed to any such changes.

Benthic monitoring during 2017 was conducted following the current Ambient Monitoring Plan (MWRA 2010) which is required under MWRA's effluent discharge permit for the Deer Island Treatment Plant. Under this plan, annual monitoring includes soft-bottom sampling for sediment conditions and infauna at 14 nearfield and farfield stations, and Sediment Profile Imaging (SPI) at 23 nearfield stations. Every third year, sediment contaminants are evaluated (at the same 14 stations where infauna and sediment condition samples are collected) and hard-bottom surveys are conducted (at 23 nearfield stations). Both of these surveys were conducted in 2017. Sediment contaminant monitoring in 2017 found no indication that toxic contaminants from the wastewater discharge are accumulating in depositional areas surrounding the outfall. Monitoring results for 2017 also indicated that hard-bottom benthic communities near the outfall have not changed substantially during the post-diversion period as compared to the baseline period.

The purpose of this report is to summarize key findings from the 2017 benthic surveys, with a focus on the most noteworthy observations relevant to understanding the potential effects of the discharge on the offshore benthic environment. Results of 2017 benthic monitoring were presented at MWRA's Annual Technical Workshop on March 23, 2018. PowerPoint presentations from this workshop are provided in Appendix A.

## 2. METHODS

Methods used to collect, analyze, and evaluate all sample types remain largely consistent with those reported for previous monitoring years (Nestler et al. 2017, Maciolek et al. 2008). Detailed descriptions of the methods are contained in the Quality Assurance Project Plan (QAPP) for Benthic Monitoring 2017–2020 (Rutecki et al. 2017). A brief overview of methods, focused on information that is not included in the QAPP, is provided in Sections 2.1 to 2.3.

### 2.1 Field Methods

Sediment and infauna sampling was conducted at 14 stations on August 2, 2017 (Figure 2-1). To aid in analyses of potential spatial patterns reported herein, these stations are grouped, based on distance from the discharge, into four "monitoring areas" within Massachusetts Bay[1]

- Transition area station FF12, located between Boston Harbor and the offshore outfall (just less than 8 km from the offshore outfall)
- Nearfield stations NF13, NF14, NF17, and NF24, located in close proximity (less than 2 km) to the offshore outfall
- Nearfield stations NF04, NF10, NF12, NF20, NF21, and NF22, located in Massachusetts Bay but farther than 2 km (and less than 5 km) from the offshore outfall
- Farfield reference stations FF01A, FF04, and FF09, located in Massachusetts Bay but farther than 13 km from the offshore outfall

Sampling effort at these stations has varied somewhat during the monitoring program. In particular, from 2004-2010 some stations were sampled only during even years (NF22, FF04 and FF09), Stations NF17 and NF12 were sampled each year, and the remaining stations were sampled only during odd years.

Sampling at Station FF04 within the Stellwagen Bank National Marine Sanctuary was conducted in accordance with Research Permit SBNMS-2016-003.

Soft-bottom stations were sampled for grain size composition, total organic carbon (TOC), and the sewage tracer *Clostridium perfringens*. In addition, samples were collected from each station for analysis of metals (Al, Fe, Ag, Cd, Cr, Cu, Hg. Ni, Pb and Zn), PCBs (20 congeners), PAHs (41 individual compounds) and pesticides (17 compounds). Infauna samples were also collected using a 0.04-$m^2$ Ted Young-modified van Veen grab, and were rinsed with filtered seawater through a 300-µm-mesh sieve.

Sediment Profile Imaging (SPI) samples were collected in triplicate at 23 nearfield stations on August 7, 2017 (Figure 2-2).

[1] The current monitoring areas include a subset of stations that were sampled before 2011. For example, the transition area formerly included station FF12 and two others that are no longer sampled.

Video camera transects (Figure 2-3) were performed as in previous years. A Benthos Mini-Rover ROV (remotely operated vehicle) was used to survey the waypoints. A GoPro Hero 4 camera mounted on the ROV was used to obtain simultaneous HD video and still images (at 10-second intervals) throughout each transect. All of the 23 hard-bottom waypoints were successfully surveyed on June 20 to 22, 2017, including an actively discharging diffuser head at the eastern end of the outfall. At least 18 minutes of both analog and high definition (HD) video footage was obtained at all but one of the waypoints. The analog video was analyzed and the HD video and stills were archived for potential future analysis.

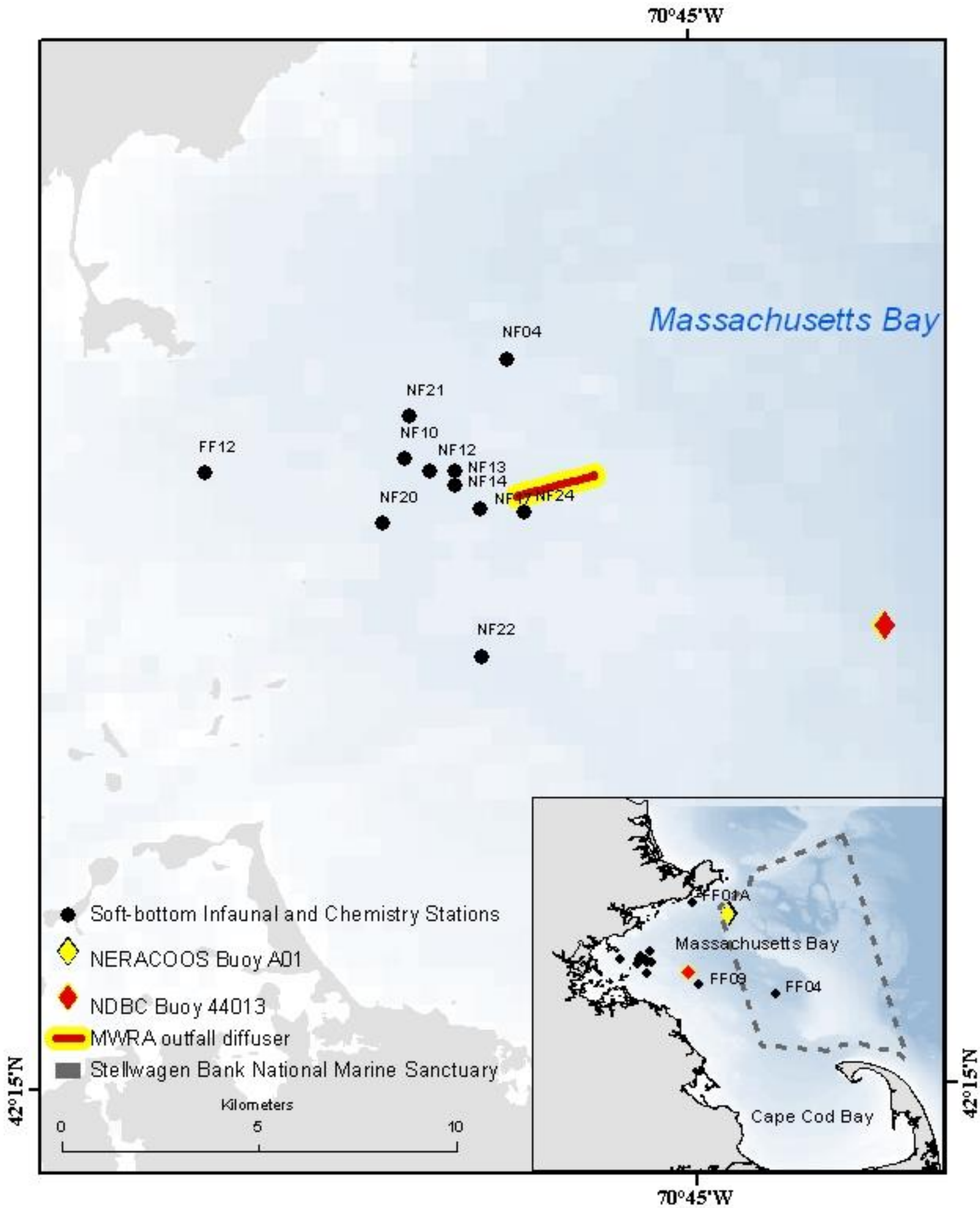


**Figure 2-1. Locations of soft-bottom sampling stations for 2017.**

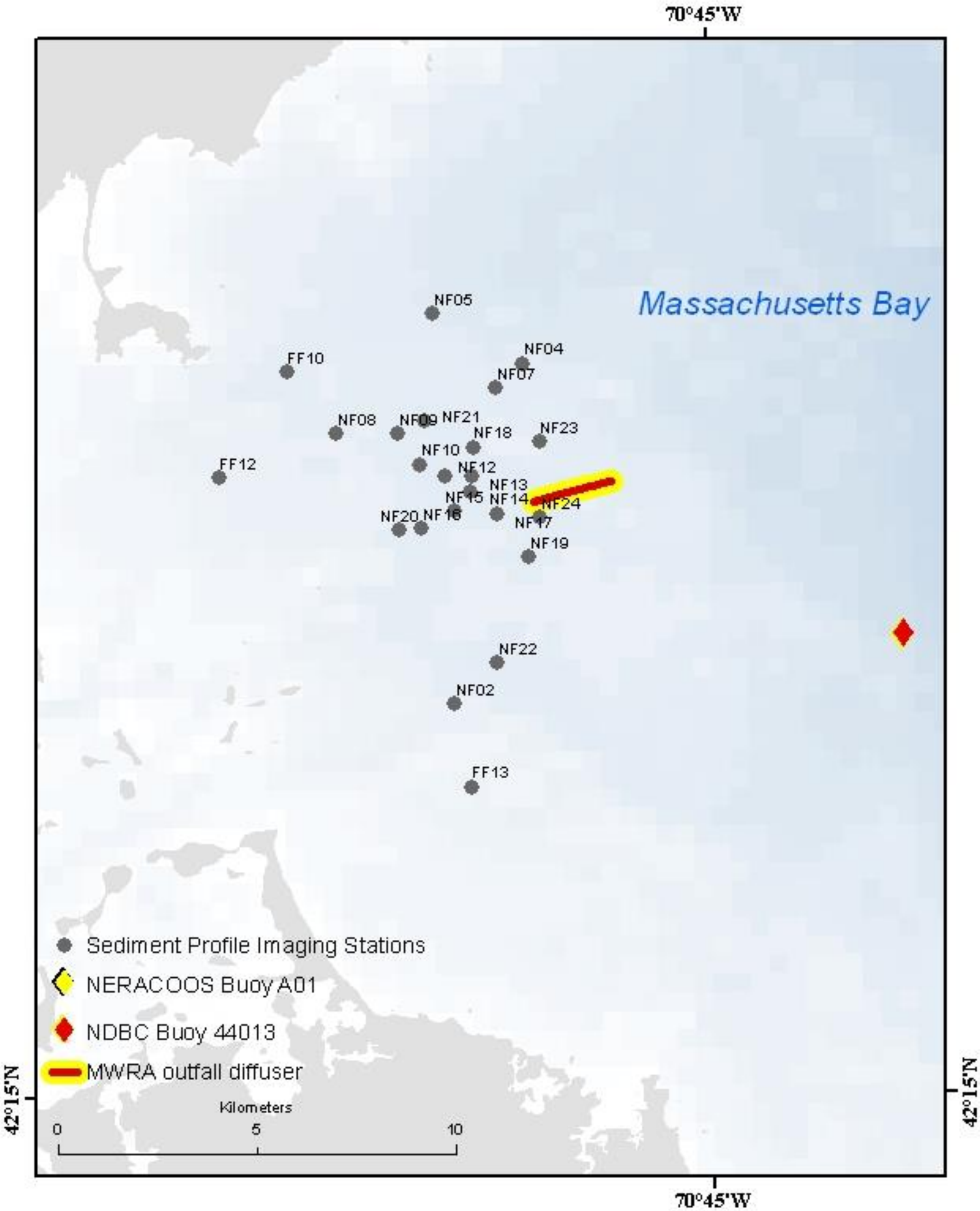


**Figure 2-2. Locations of sediment profile imaging stations for 2017.**

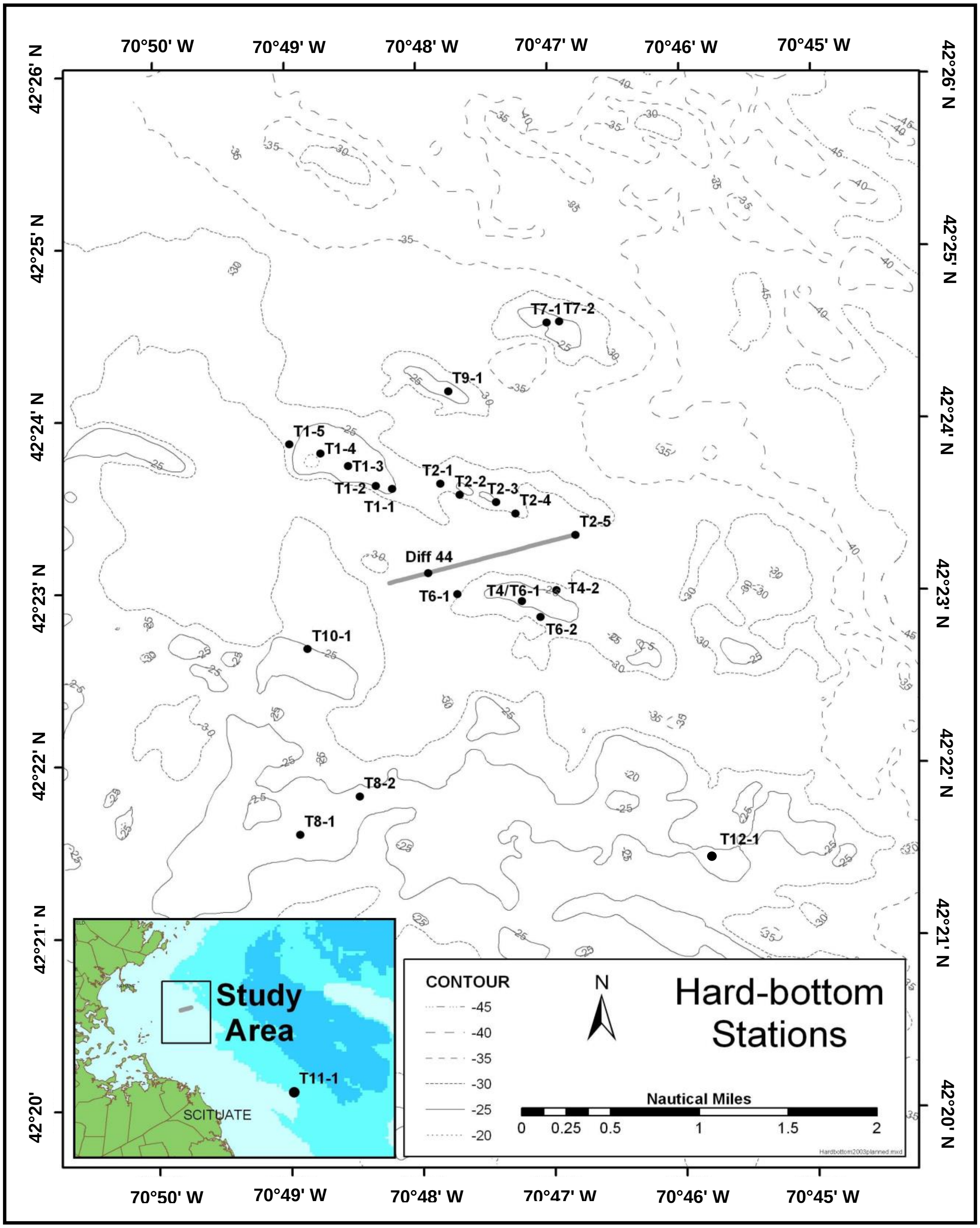


**Figure 2-3. Locations of hard bottom video transects for 2017.**

## 2.2 Laboratory Methods

All bacteriological, physical and chemical analyses were conducted by MWRA's DLS Laboratory following the procedures described in Constantino et al. (2014). All sample processing, including sorting, identification, and enumeration of infaunal organisms, was done following methods consistent with the QAPP (Rutecki et al. 2017).

## 2.3 Data Handling, Reduction, and Analysis

All benthic data were extracted directly from the HOM database and imported into Excel. Data handling, reduction, graphical presentations and statistical analyses were performed as described in the QAPP (Rutecki et al. 2017) or by Maciolek et al. (2008).

Additional multivariate techniques were used to evaluate infaunal communities. Multivariate analyses were performed using PRIMER v6 (Plymouth Routines in Multivariate Ecological Research) software to examine spatial patterns in the overall similarity of benthic assemblages in the survey area (Clarke 1993, Warwick 1993, Clarke and Green 1988). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group average linking and ordination by non-metric multidimensional scaling (MDS). Bray-Curtis similarity was used as the basis for both classification and ordination. Prior to analyses, infaunal abundance data were fourth-root transformed to ensure that all taxa, not just the numerical dominants, would contribute to similarity measures.

Cluster analysis produces a dendrogram that represents discrete groupings of samples along a scale of similarity. This representation is most useful when delineating among sites with distinct community structure. MDS ordination produces a plot or "map" in which the distance between samples represents their rank ordered similarities, with closer proximity in the plot representing higher similarity. Ordination provides a more useful representation of patterns in community structure when assemblages vary along a steady gradation of differences among sites. Stress provides a measure of adequacy of the representation of similarities in the MDS ordination plot (Clarke 1993). Stress levels less than 0.05 indicate an excellent representation of relative similarities among samples with no prospect of misinterpretation. Stress less than 0.1 corresponds to a good ordination with no real prospect of a misleading interpretation. Stress less than 0.2 still provides a potentially useful two-dimensional picture, while stress greater than 0.3 indicates that points on the plot are close to being arbitrarily placed. Together, cluster analysis and MDS ordination provide a highly informative representation of patterns of community-level similarity among samples. The "similarity profile test" (SIMPROF) was used to provide statistical support for the identification of faunal assemblages (i.e., selection of cluster groups). SIMPROF is a permutation test of the null hypothesis that the groups identified by cluster analysis (samples included under each node in the dendrogram) do not differ from each other in multivariate structure.

To help with assessment of spatial patterns, stations have been grouped into regions according to distance from the outfall. The monitoring areas include nearfield stations <2 km from the outfall, nearfield stations > 2 km from the outfall, a transition station, and farfield stations (see Section 2.1).

### 2.3.1 Data Reduction and Statistics for SPI Images

Quantitative SPI parameters were averaged from the three replicate images. For categorical parameters the median value of the three replicate images was assigned to a station.

Since the selection of station locations in the nearfield was non-random, fixed-effect nominal logistic models were used to analyze patterns in categorical data (Agresti 1990). For continuous variables, analysis of variance (ANOVA) and analysis of covariance (ANCOVA) was used to test for differences within and between quantitative parameters. Normality was checked with the Shapiro–Wilk test and homogeneity of variance with Bartlett's test. If variance was not homogeneous, either non-parametric Kruskal-Wallis test or Van Der Waerden test, which converts the ranks from a standard Kruskal-Wallis test to quantiles of the standard normal distribution, or Welch ANOVA, which allows standard deviations to be unequal, was used in testing for mean or ranked differences (Zar 1999). Tukey's HSD (Honest Significant Difference) test was used for multiple mean comparisons from ANOVA and ANCOVA. Trends in quantitative variables were tested using simple linear regression and segmented linear regression with two segments separated by a breakpoint. Significance of odds was tested using likelihood ratio chi-square. Statistical tests were conducted using JMP® (SAS® Institute, Inc., Cary, NC).

# 3. RESULTS AND DISCUSSION

## 3.1 Sediment Conditions

### 3.1.1 *Clostridium perfringens*, Grain Size, and Total Organic Carbon

Sediment conditions were characterized by three parameters measured during 2017 at each of the 14 sampling stations: (1) *Clostridium perfringens*, (2) grain size (gravel, sand, silt, and clay), and (3) total organic carbon (Table 3-1).

Spores of the anaerobic bacterium *Clostridium perfringens* provide a sensitive tracer of effluent solids. Temporal analyses of *C. perfringens* at the 14 sampling sites demonstrated that a sharp increase occurred coincident with diversion of effluent to the offshore outfall at sites within two kilometers from the diffuser (Figure 3-1). *C. perfringens* concentrations have declined or remained comparable to the baseline at all other monitoring locations during the post-diversion period. *C. perfringens* counts (reported as colony forming units per gram dry weight, normalized to percent fines) in samples collected during 2017 were slightly lower than the previous year at all locations except for sites within two kilometers from the discharge (Figure 3-1). As in past years during the post-diversion period, *C. perfringens* concentrations during 2017 continued to indicate a footprint of the effluent plume at sites closest to the discharge. Normalized *C. perfringens* spore counts in samples collected in 2017 were highest at station NF13 located within two kilometers of the outfall (Table 3-1, Figure 3-2). Sensitive statistical analyses conducted in support of the outfall benthic monitoring reports for 2006 and 2007 (Maciolek et al. 2007, 2008) confirmed that findings of higher *C. perfringens* at stations close to the outfall were statistically significant and consistent with an impact of the outfall discharge.

Sediment texture in 2017 varied considerably among the 14 stations, ranging from almost entirely sand (e.g., NF17, NF13, and NF04) to predominantly silt and clay (i.e., FF04), with most stations having mixed sediments (Figure 3-3). Sediment texture has remained generally consistent over time, with relatively small year-to-year changes in the percent fine sediments at most stations (Figure 3-4). Year to year variability in sediment texture at the Massachusetts Bay stations has typically been associated with strong storms. Bothner et al. (2002) reported that sediment transport at water depths less than 50 meters near the outfall site in Massachusetts Bay occurs largely as a result of wave-driven currents during strong northeast storm events.

Concentrations of TOC in 2017 remained similar to values reported in prior years at most stations (Figure 3-5). Concentrations of TOC track closely to percent fine sediments (i.e., silt + clay), with higher TOC values generally associated with higher percent fines (compare Figures 3-4 and 3-5). To further assess spatial patterns in TOC concentrations while accounting for the association between TOC and percent fine sediments, TOC values were normalized to percent fines (Figure 3-6). Normalized TOC concentrations were not consistently higher during the post-diversion period than during the baseline period at sites closest to the discharge (Figures 3-6 and 3-7).

*C. perfringens* counts continue to provide evidence of effluent solids depositing near the outfall. There is no indication, however, that the wastewater discharge has resulted in changes to the sediment grain size composition at the Massachusetts Bay sampling stations, and there is no indication of organic enrichment. TOC concentrations remain comparable to, or lower than, values reported during the baseline period, even at sites closest to the outfall (Figures 3-7 and 3-8).

**Table 3-1. 2017 monitoring results for sediment condition parameters.**

| Monitoring Area | Station | Clostridium perfringens (cfu/g dry/%fines) | Total Organic Carbon (%) | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Percent Fines (Silt + Clay) |
|---|---|---|---|---|---|---|---|---|
| Transition Area | FF12 | 9.1 | 0.46 | 1.4 | 73.6 | 20.6 | 4.3 | 25.0 |
| Nearfield (<2 km from outfall) | NF13 | 800.0 | 0.07 | 0.0 | 98.0 | 1.0 | 1.1 | 2.1 |
| | NF14 | 28.4 | 0.24 | 34.2 | 57.1 | 5.7 | 3.0 | 8.6 |
| | NF17 | 8.9 | 0 | 0 | 94.5 | 4.7 | 0.8 | 5.5 |
| | NF24 | 41.9 | 0.68 | 2.8 | 76.9 | 16.8 | 3.6 | 20.4 |
| Nearfield (>2 km from outfall) | NF04 | 46.5 | 0.06 | 2.0 | 95.3 | 1.4 | 1.3 | 2.7 |
| | NF10 | 54.1 | 0.35 | 1.8 | 63.4 | 27.1 | 7.7 | 34.8 |
| | NF12 | 39.9 | 0.72 | 0 | 32.2 | 53.9 | 14.0 | 67.9 |
| | NF20 | 120.4 | 0.63 | 44.5 | 36.9 | 12.7 | 5.9 | 18.6 |
| | NF21 | 38.9 | 0.61 | 0 | 48.1 | 42.1 | 9.8 | 51.9 |
| | NF22 | 12.5 | 0.73 | 23.1 | 52.7 | 18.2 | 6.0 | 24.2 |
| Farfield | FF01A | 1.2 | 0.19 | 0.3 | 88.5 | 4.1 | 7.2 | 11.2 |
| | FF04 | 6.1 | 2.14 | 0 | 10.0 | 66.2 | 23.8 | 90.0 |
| | FF09 | 51.9 | 0.40 | 0.2 | 89.1 | 6.8 | 4.0 | 10.8 |

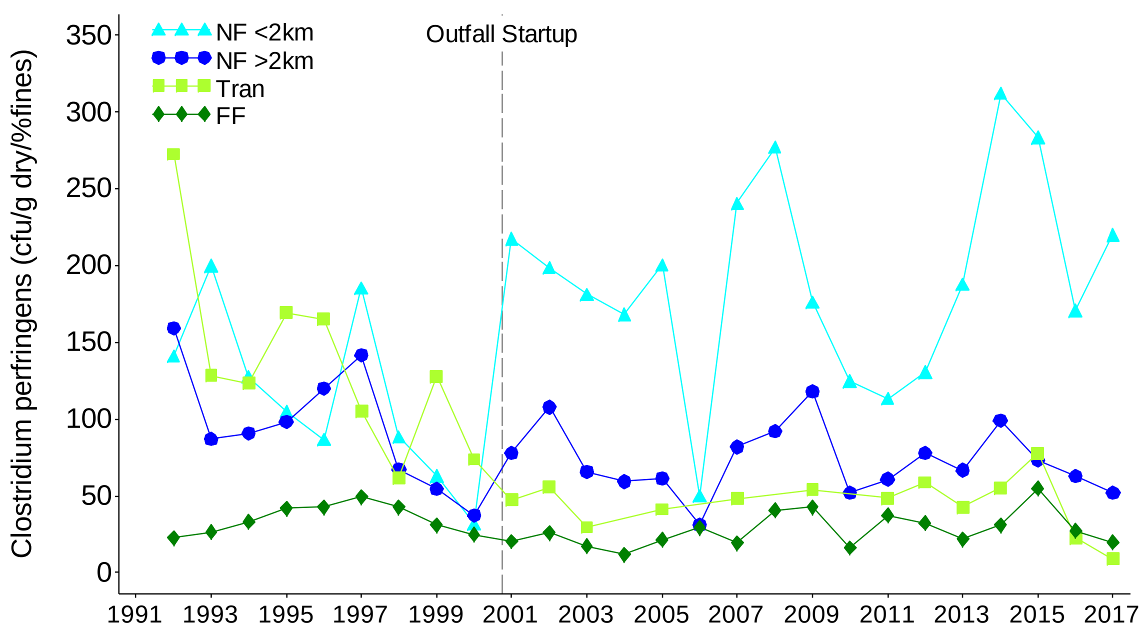


**Figure 3-1. Mean concentrations of *Clostridium perfringens* in four areas of Massachusetts Bay, 1992 to 2017. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**

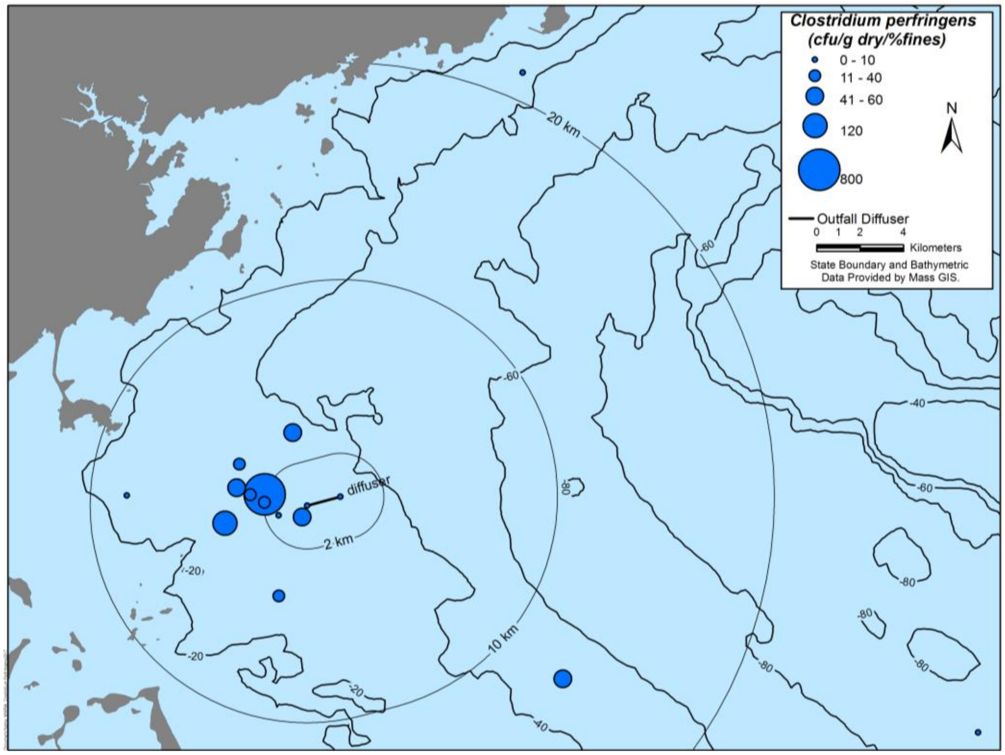


**Figure 3-2. 2017 monitoring results for *Clostridium perfringens*.**

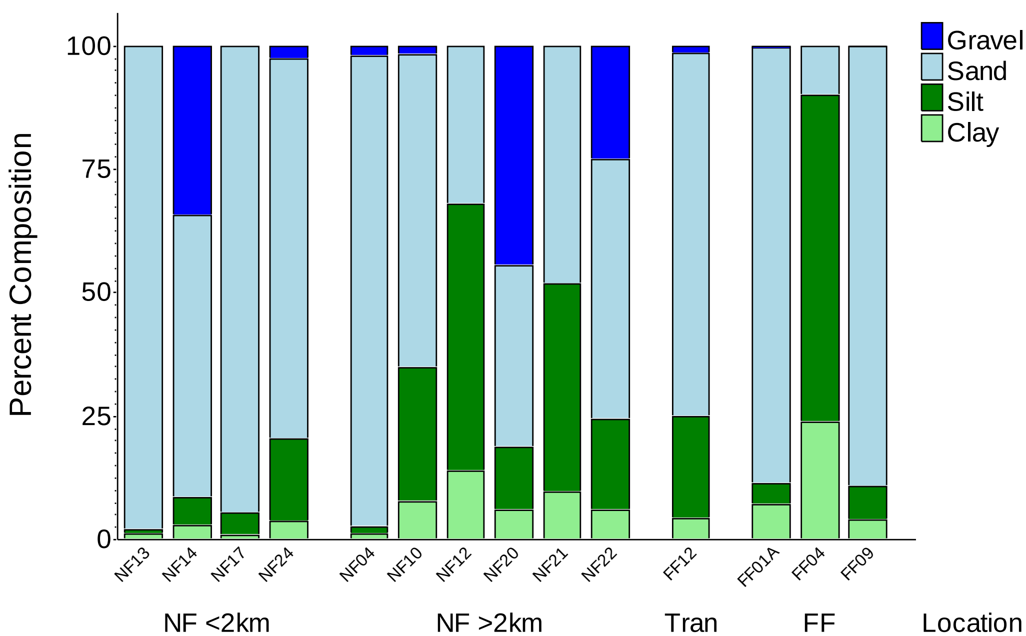


**Figure 3-3. 2017 monitoring results for sediment grain size.**

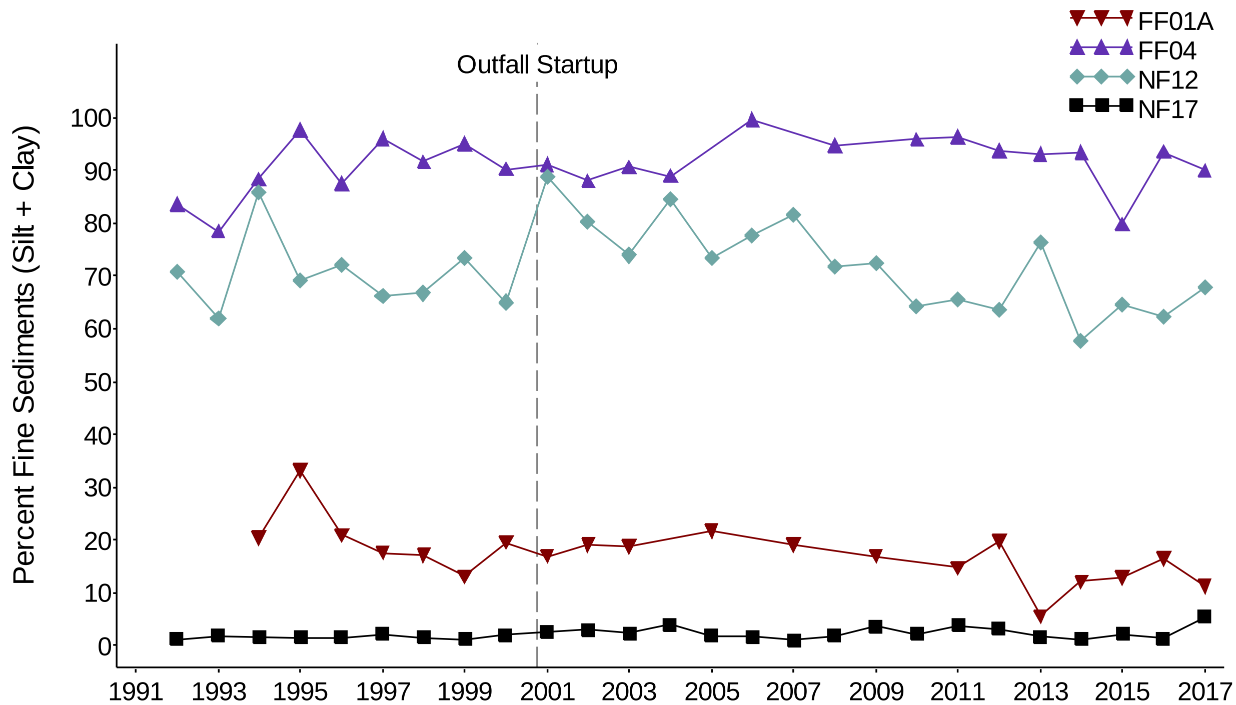


**Figure 3-4. Mean percent fine sediments at FF01A, FF04, NF12 and NF17; 1992 to 2017.**

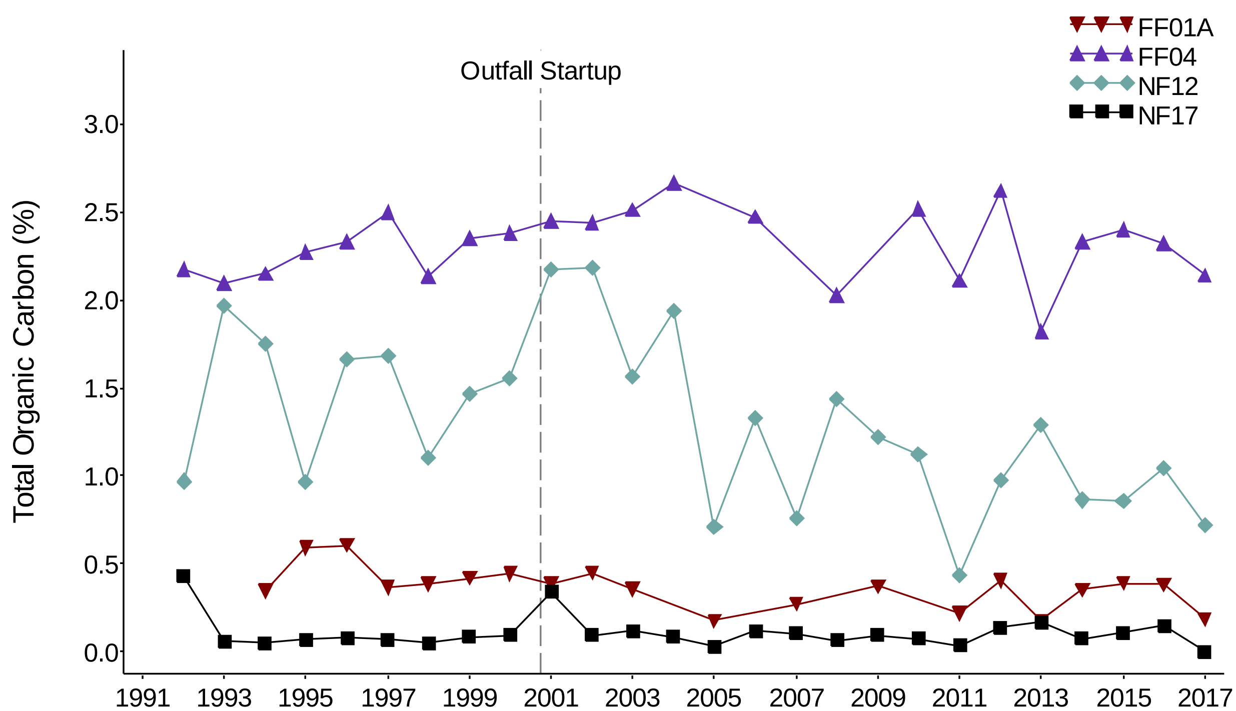


**Figure 3-5. Mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2017.**

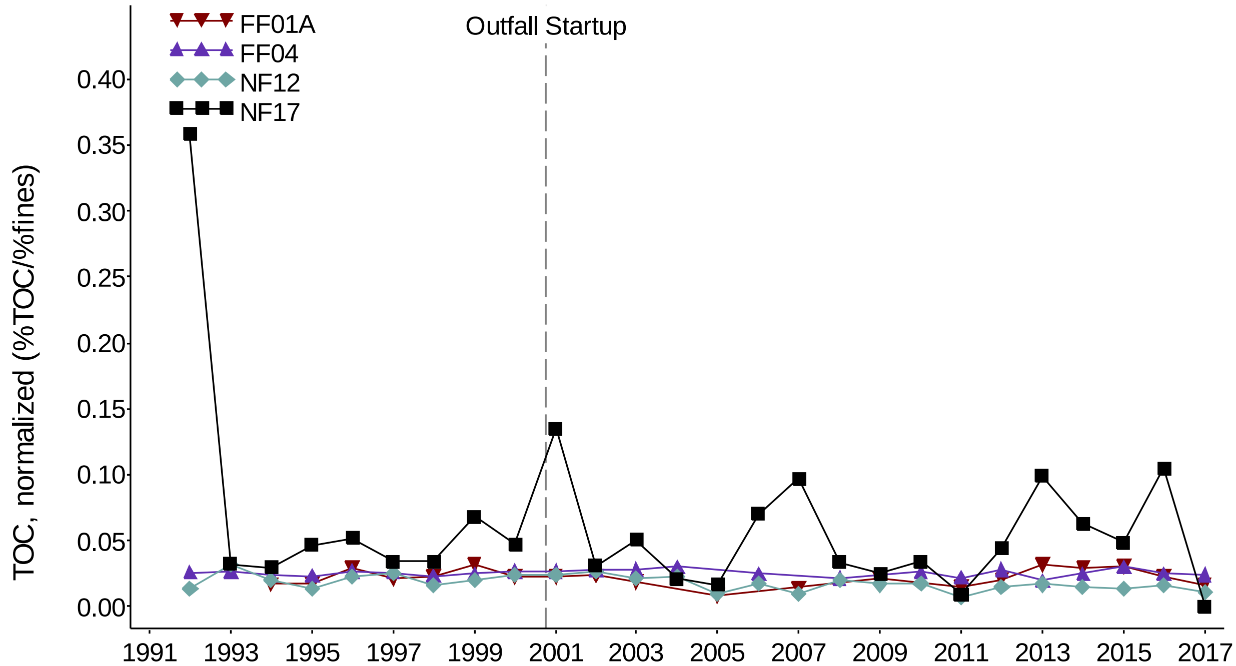


**Figure 3-6. Normalized mean concentrations of TOC at four stations in Massachusetts Bay, 1992 to 2017.**

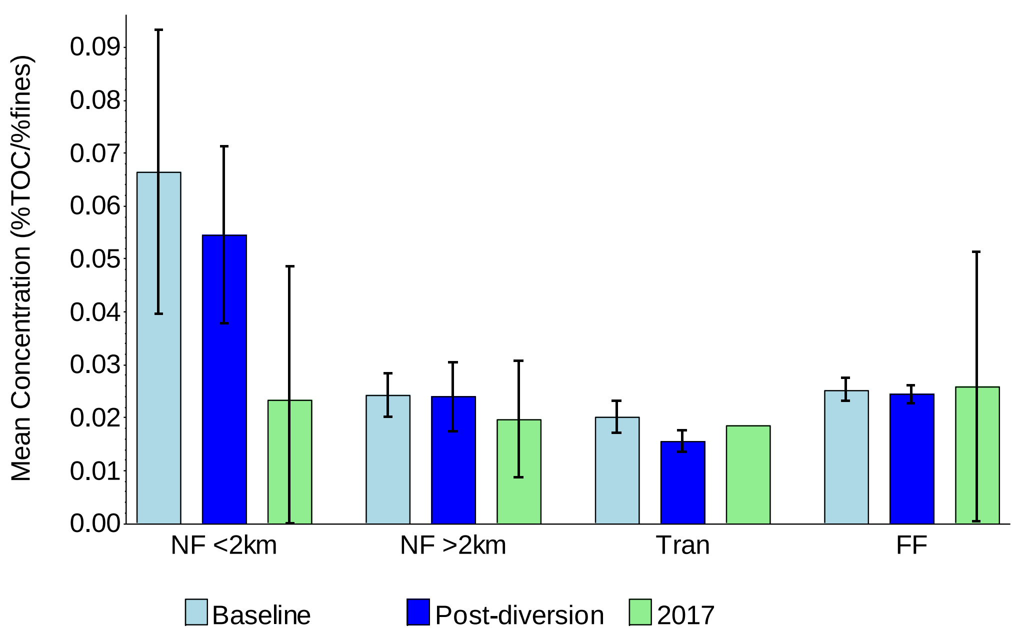


**Figure 3-7. Normalized mean concentrations of TOC at four areas in Massachusetts Bay during the baseline (1992 to 2000) and post-diversion (2001 to 2017) periods compared to 2017. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**

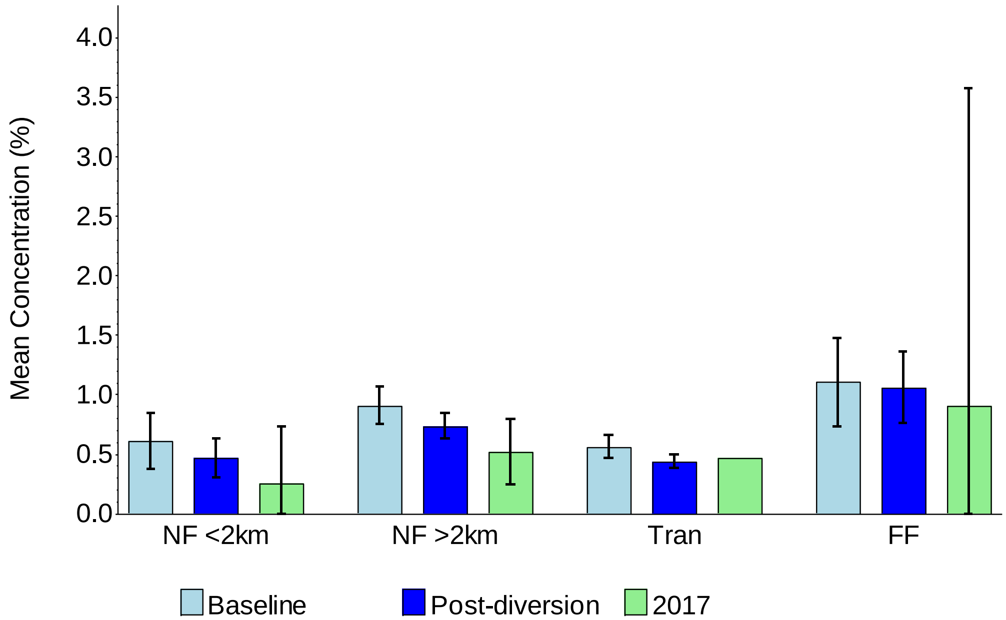


**Figure 3-8. Mean (with 95% confidence intervals) concentrations of TOC at four areas in Massachusetts Bay during the baseline (1992-2000) and post-diversion (2001 to 2017) compared to 2017.**

### 3.1.2 Anthropogenic Contaminants

Sediment samples collected during 2017 were analyzed for anthropogenic contaminants including both metals and organics. Thresholds have been established for 26 different sediment contaminants. No Contingency Plan threshold exceedances were reported for any sediment contaminants in 2017. For 22 of the 26 contaminants with thresholds, the 2017 nearfield average concentration was below the minimum annual average reported during the baseline period. The "Effects Range Low" (ER-L) sediment quality guidelines from NOAA, based on the toxicity of contaminants to infaunal organisms, provide a useful measure against which to compare sediment contaminant concentrations (Long et al. 1995). In 2017, mercury, nickel, and total PAH values exceeded the ER-L limit at one or more stations (Table 3-2). Six of the 14 stations sampled in Massachusetts Bay had values for at least one contaminant that exceeded the ER-Ls, and none of these stations are located within two kilometers from the discharge. The ER-M (effects range median) represents a contaminant level above which adverse impacts to benthic organisms are often detected (Long et al. 1995). No contaminant values reported during 2017 exceeded the ER-M sediment quality guideline (Table 3-2). As has been seen in the past, higher contaminant levels are strongly correlated with smaller sediment particle sizes. The two stations with the highest contaminant concentrations, NF12 and NF21, have the highest percent fines of the nearfield stations, and are relatively close to Boston Harbor, the main historic source for contaminants in Massachusetts Bay. There continues to be no indication of contaminants from effluent accumulating in the sediments. The concentrations of most sediment contaminants were lower in 2017 than in previous years; overall, these results suggest that the levels of most contaminants that are measured by this program continue to decline (Figures 3-9 to 3-12).

**Table 3-2. Sediment contaminant values that exceeded ER-L levels in 2017.**

| Parameter | Units | Nearfield (>2 km from outfall) | | | | | Farfield | Sediment Quality Guidelines (SQGs) | |
|---|---|---|---|---|---|---|---|---|---|
| | | NF10 | NF12 | NF20 | NF21 | NF22 | FF04 | ER-L | ER-M |
| **Mercury** | mg/kg dry | 0.15 | 0.40 | 0.19 | 0.35 | 0.17 | 0.20 | 0.15 | 0.71 |
| **Nickel** | mg/kg dry | | | | | | 30.2 | 20.9 | 51.6 |
| **Total PAH** | ng/kg dry | | 8305 | 5043 | 8370 | | | 4022 | 44792 |

Highest reported value in 2017

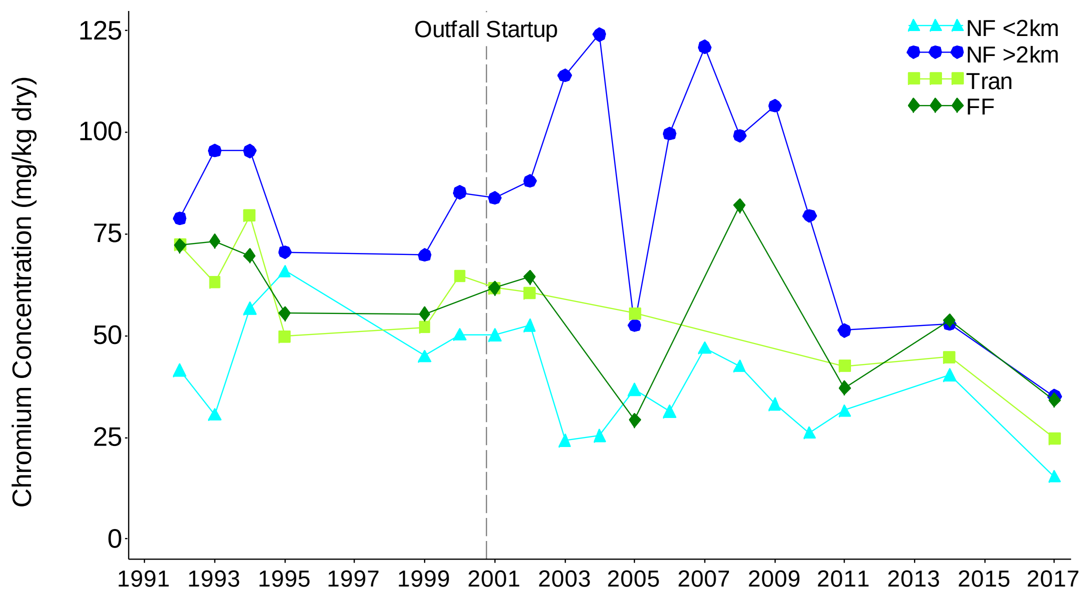


**Figure 3-9. Mean concentrations of Chromium at four areas in Massachusetts Bay, 1992 to 2017.**

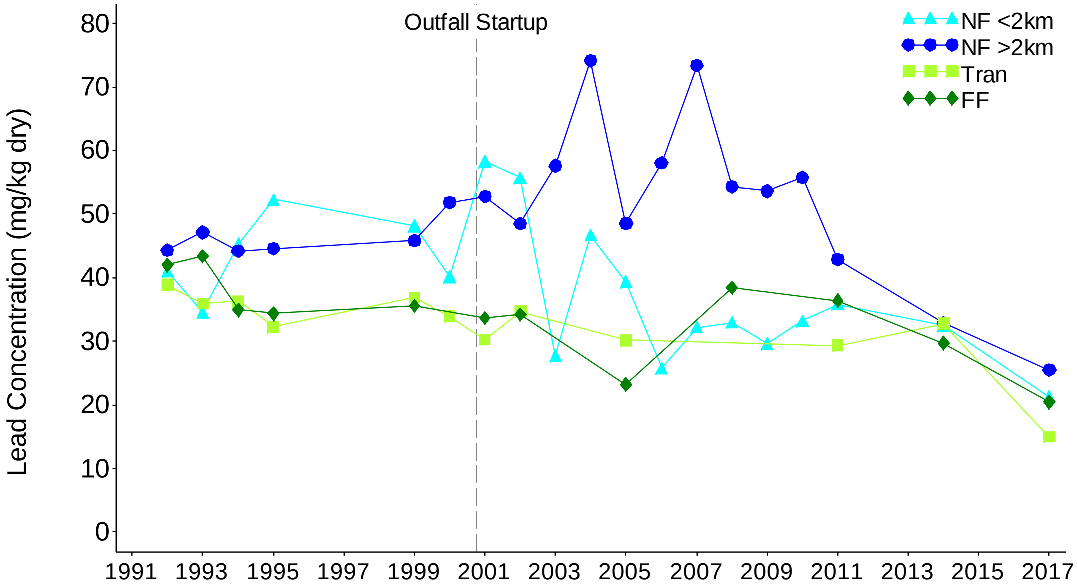


**Figure 3-10. Mean concentrations of Lead at four areas in Massachusetts Bay, 1992 to 2017.**

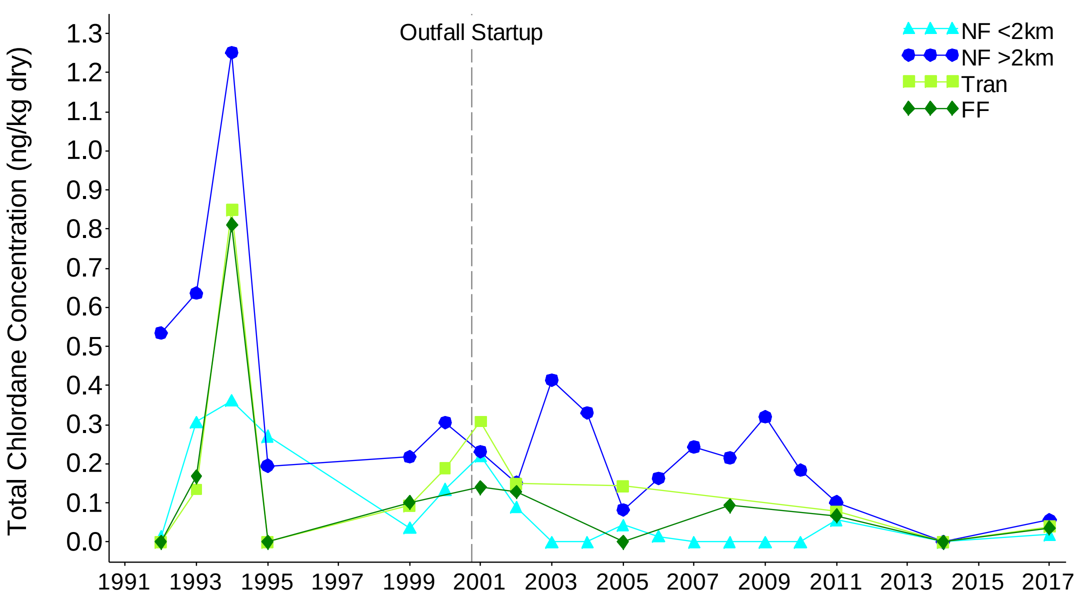


**Figure 3-11. Mean concentrations of Total Chlordane at four areas in Massachusetts Bay, 1992 to 2017.**

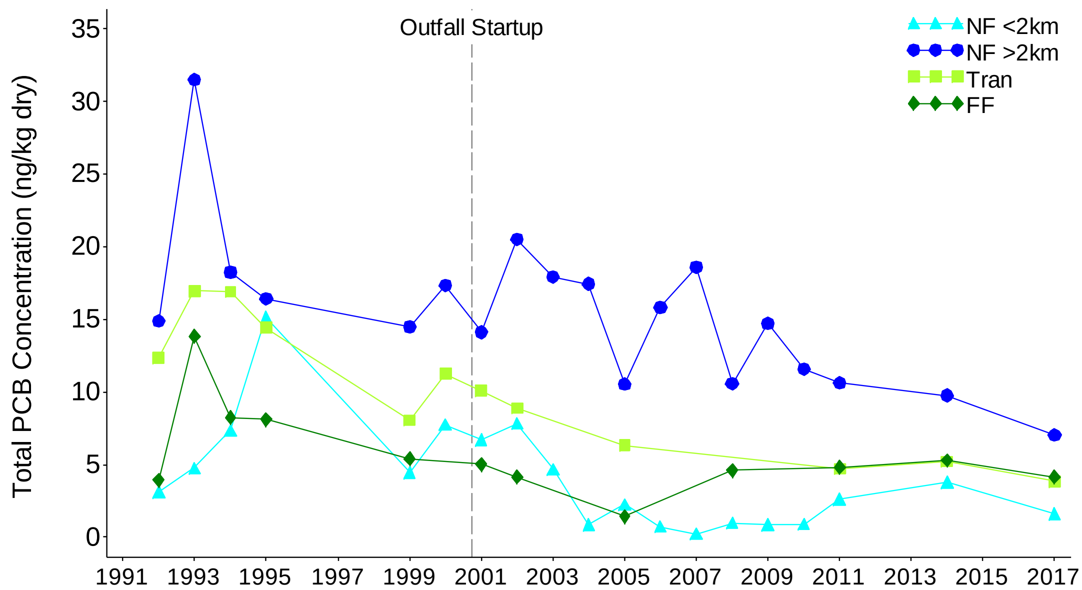


**Figure 3-12. Mean concentrations of Total PCB at four areas in Massachusetts Bay, 1992 to 2017.**

## 3.2 Benthic Infauna

### 3.2.1 Community Parameters

A total of 23,038 infaunal organisms were counted from the 14 samples in 2017. Organisms were classified into 214 discrete taxa; 188 of those taxa were species-level identifications. The abundance values reported herein reflect the total counts from both species and higher taxonomic groups, while all diversity measures and multivariate analyses are based on the species-level identifications only (Table 3-3).

Total abundance values in 2017 were higher than the previous year at all areas in Massachusetts Bay (Figure 3-13). Abundance at Station FF12 (the only station in the "Transition Area"), remained higher than means for other areas in the Bay for a fourth consecutive year (Figure 3-13) although similar abundances were observed at some individual nearfield stations (Table 3-3). The numbers of species per sample in 2017 were also higher than in 2016 at all locations; as seen since 2014, mean values remained relatively similar across all areas of the Bay (Figure 3-14). There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2017 (Table 3-4). Upper limit exceedances (compared to baseline period values) had been reported for Shannon-Wiener Diversity (H') and Pielou's Evenness (J') each year from 2010 to 2014. Since then, diversity measures have been within the range in baseline values. In March 2017, the EPA approved MWRA's interim request for modification to the Contingency Plan that removed the upper level thresholds for infaunal diversity parameters because this type of exceedance is not indicative of an outfall effect. Permanent approval for the change was granted in

February 2018. In 2017, the values for both H' and J' were just below the upper threshold limit (Figures 3-15 and 3-16).

Spatial and temporal patterns of abundance, species richness, species diversity and evenness generally support the conclusion that there is no evidence of negative impacts caused by operation of the offshore outfall.

**Table 3-3. 2017 monitoring results for infaunal community parameters.**

| Monitoring Area | Station | Total Abundance (per grab) | Number of Species (per grab) | Log-series alpha | Shannon-Wiener Diversity (H′) | Pielou's Evenness (J') |
|---|---|---|---|---|---|---|
| Transition Area | FF12 | 2721 | 10.45 | 3.66 | 0.63 | 58 |
| Nearfield (<2 km from outfall) | NF13 | 1672 | 15.69 | 4.04 | 0.65 | 73 |
| | NF14 | 1623 | 15.19 | 4.02 | 0.65 | 71 |
| | NF17 | 859 | 13.62 | 3.81 | 0.66 | 56 |
| | NF24 | 2748 | 12.86 | 3.91 | 0.64 | 69 |
| Nearfield (>2 km from outfall) | NF04 | 898 | 12.39 | 3.95 | 0.69 | 53 |
| | NF10 | 2144 | 12.43 | 4.11 | 0.69 | 64 |
| | NF12 | 863 | 14.06 | 4.03 | 0.69 | 58 |
| | NF20 | 3121 | 13.17 | 3.55 | 0.58 | 72 |
| | NF21 | 1672 | 14.03 | 4.31 | 0.71 | 67 |
| | NF22 | 1723 | 11.59 | 3.87 | 0.66 | 58 |
| Farfield | FF01A | 987 | 14.82 | 4.35 | 0.73 | 62 |
| | FF04 | 728 | 10.31 | 3.53 | 0.65 | 44 |
| | FF09 | 1279 | 24.21 | 4.86 | 0.74 | 94 |

**Table 3-4. Infaunal monitoring threshold results, August 2017 samples.**

| Parameter | Threshold range | | Result | Exceedance? |
|---|---|---|---|---|
| | Low | High | | |
| **Total species** | 43.0 | 81.9 | 63.55 | No |
| **Log-series Alpha** | 9.42 | - | 13.23 | No |
| **Shannon-Weiner H′** | 3.37 | - | 3.93 | No |
| **Pielou's J'** | 0.57 | - | 0.66 | No |
| **Apparent RPD** | 1.18 | NA | 4.12 | No |
| **Percent opportunists** | 10% (Caution)<br>25% (Warning) | | 1.23 | No |

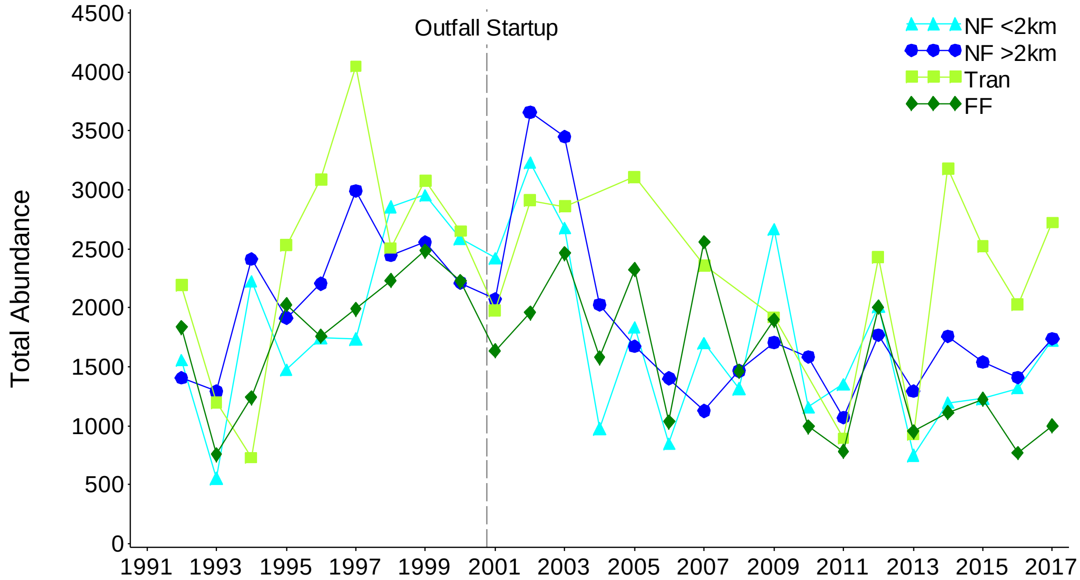


**Figure 3-13. Mean infaunal abundance per sample at four areas of Massachusetts Bay, 1992 to 2017. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**

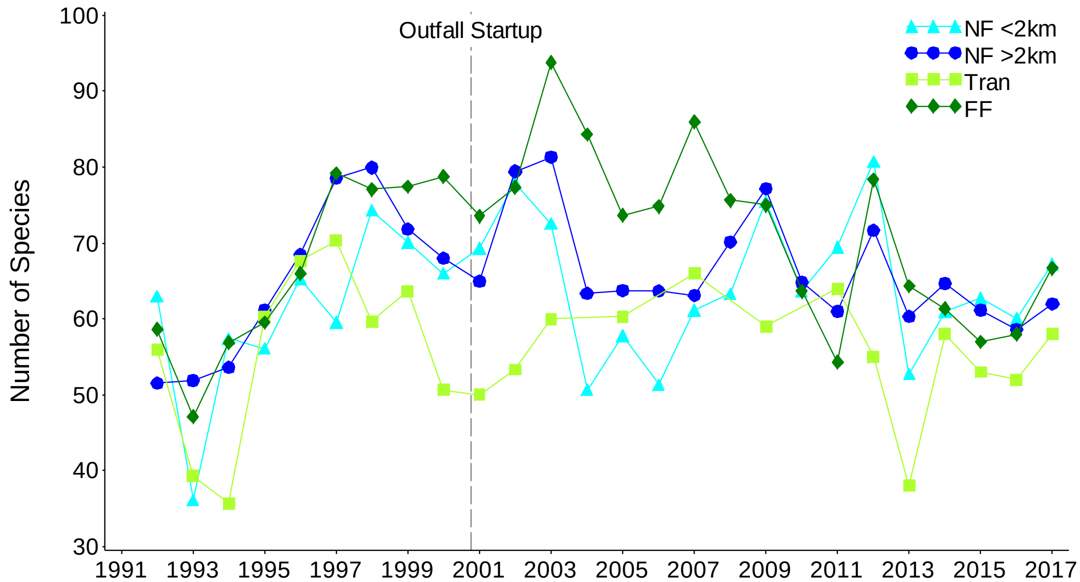


**Figure 3-14. Mean number of species per sample at four areas of Massachusetts Bay, 1992 to 2017. Tran=Transition area; NF<2km=nearfield, less than two kilometers from the outfall; NF>2km=nearfield, more than two kilometers from the outfall; FF=farfield.**

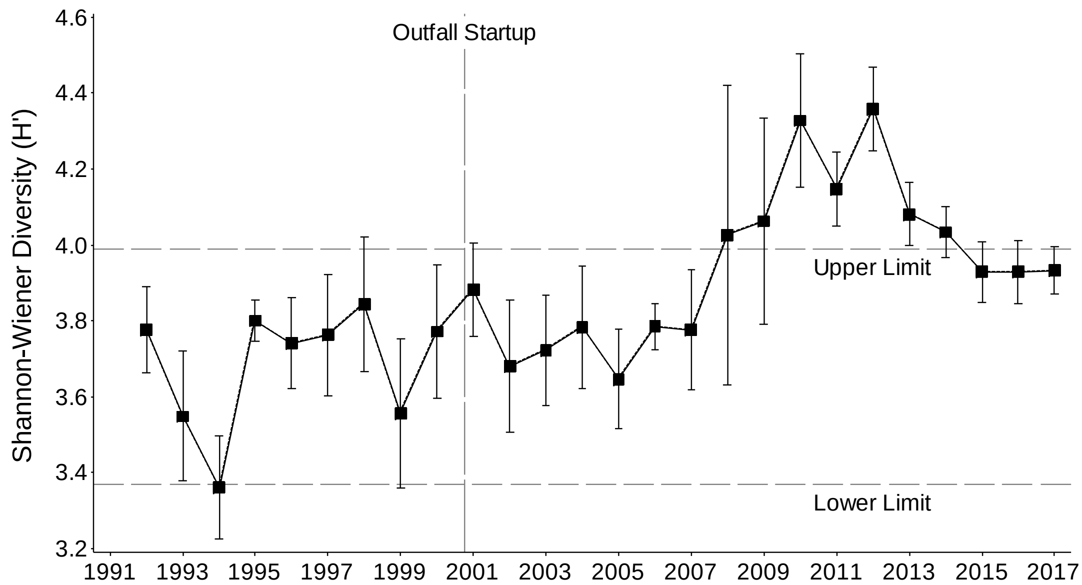


**Figure 3-15. Mean (and 95% confidence intervals) Shannon-Wiener Diversity (H′) at nearfield stations in comparison to threshold limits, 1992 to 2017. The nearfield annual means and associated threshold limits are both based on the list of stations sampled following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010).**

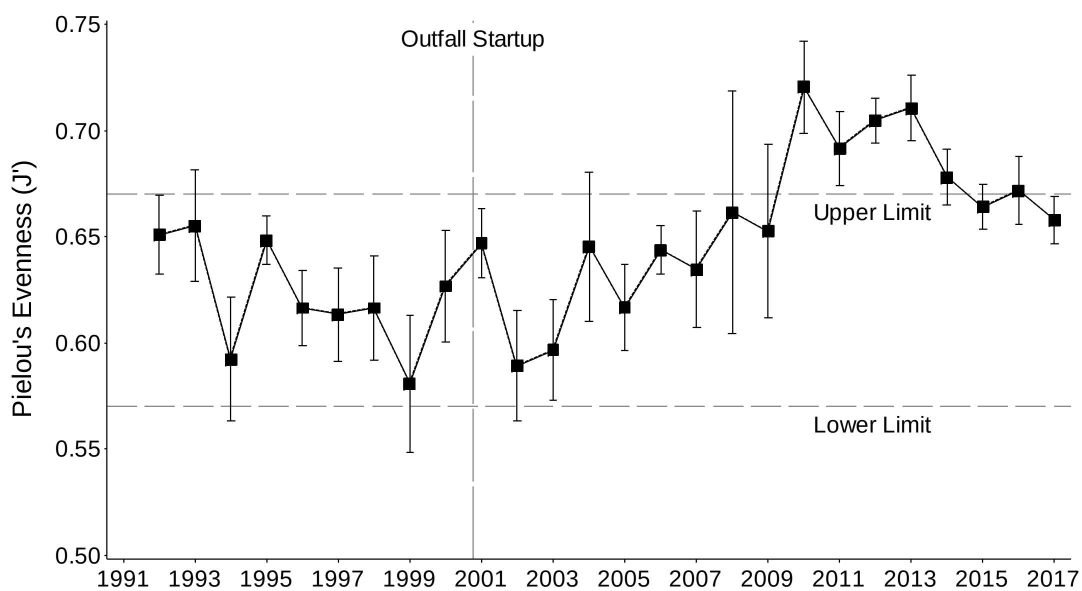


**Figure 3-16. Mean (and 95% confidence intervals) Pielou's Evenness (J′) at nearfield stations in comparison to threshold limits, 1992 to 2017. The nearfield annual means and associated threshold limits are both based on the list of stations sampled following the 2010 revision to the Ambient Monitoring Plan (MWRA 2010).**

### 3.2.2 Infaunal Assemblages

Multivariate analyses based on Bray-Curtis Similarity were used to assess spatial patterns in the faunal assemblages at the Massachusetts Bay sampling stations. Two main assemblages (Groups I and II) were identified in a cluster analysis of the 14 samples from 2017 (Figure 3-17). An outlier assemblage was found at Station FF04. The main groups were distinguished primarily based on the mean abundances and dominant taxa. Abundances at the stations included in Group I were generally low while abundances in Group II were generally two to three times higher. All assemblages were mostly dominated by polychaetes (Table 3-5). While several species (*Mediomastus californiensis*, *Tharyx acutus* and *Aricidea catherinae*) were among the dominants in most groups, three species (*Polygordius jouinae, Spiophanes bombyx* and *Exogone hebes*) were prevalent only in Group I and four species (*Kirkegaardia hampsoni*, *Ninoe nigripes*, *Levinsenia gracilis* and *Prionospio steestrupi*) were prevalent on in Group II. The Group I assemblage included one subgroup (Group IA:  Stations NF04 and NF13). Stations NF04 and NF17 were closely related to Group IA, but each station differed somewhat in terms of species composition.  The Group II assemblage contained four sub-assemblages (two of them, FF09 and FF12, were single-sample outliers) that could be differentiated by species composition and total abundance. Species richness at Station FF09 was the highest of any group.  The relatively deep Station FF04 was characterized by low abundances and species richness. Dominant species there, including *Levinsenia gracilis, Cossura longocirrata*, and *Chaetozone anasimus*, are characteristic of the soft sediment community observed throughout Stellwagen Basin prior to the monitoring plan changes that took effect in 2011 (e.g., Maciolek et al. 2008).

Both main assemblages occurred at the four stations within two kilometers of the discharge as well as at stations more than two kilometers from the discharge (Figure 3-18). Thus, stations closest to the discharge were not characterized by a unique faunal assemblage reflecting effluent impacts. Comparisons of faunal distribution to habitat conditions indicated that patterns in the distribution of faunal assemblages follow differences in habitat types at the sampling stations. This finding was exemplified by the comparisons among assemblages and sediment types at the sampling stations (Figure 3-19).

Patterns identified in these analyses were highly consistent with previous years. No evidence of impacts from the offshore outfall on infaunal communities in Massachusetts Bay was found.

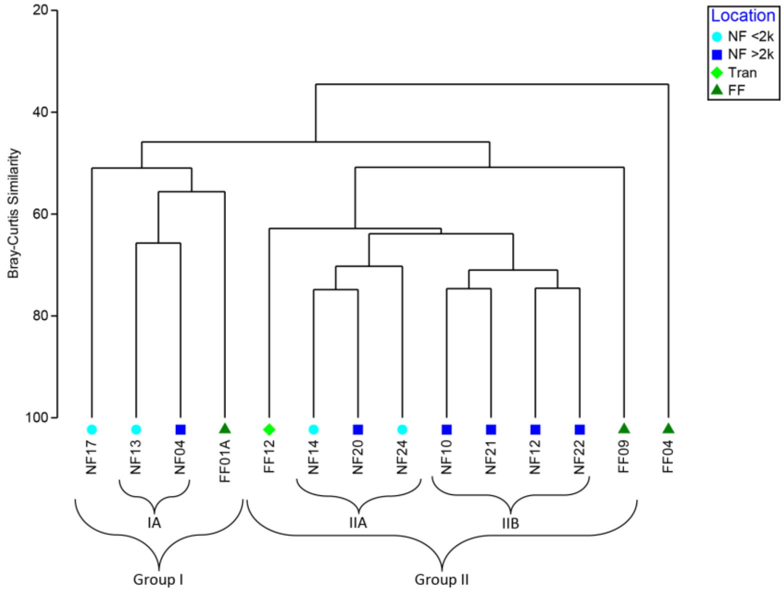


**Figure 3-17. Results of cluster analysis of the 2017 infauna samples.**

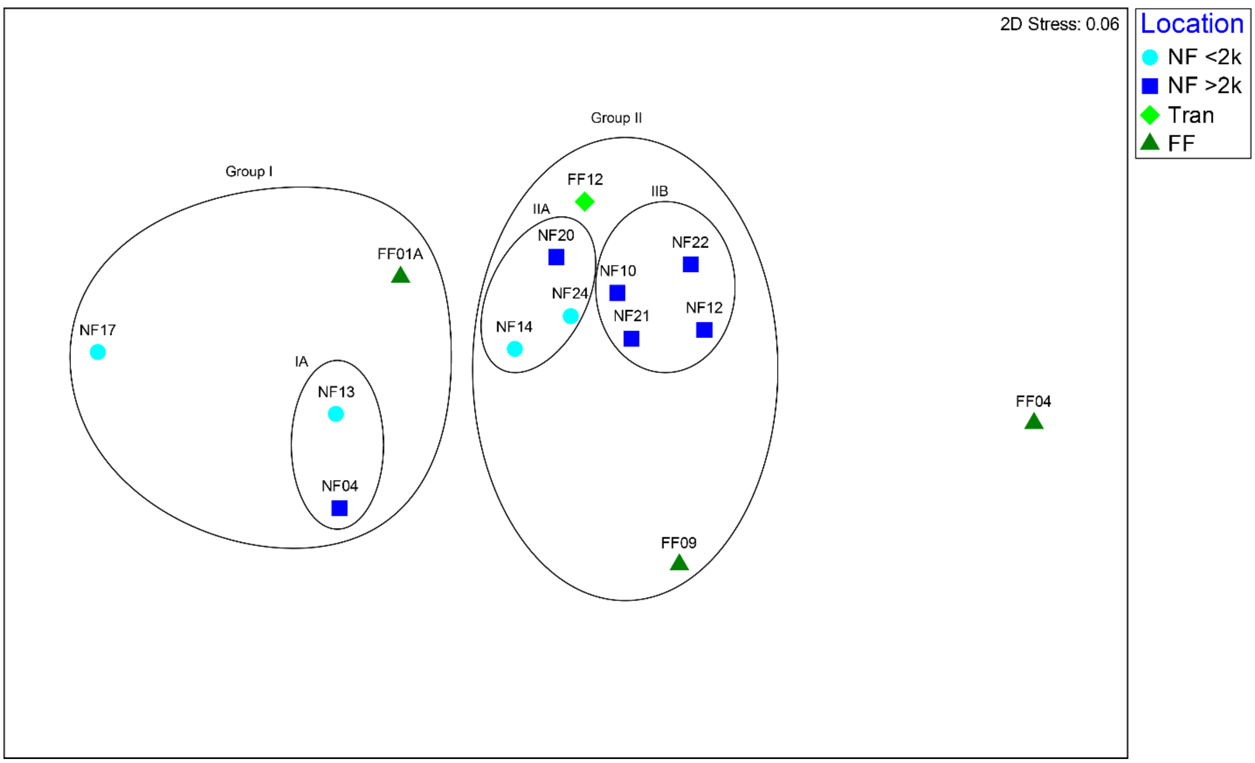


**Figure 3-18. Results of a MDS ordination of the 2017 infauna samples from Massachusetts Bay showing distance from the outfall.**

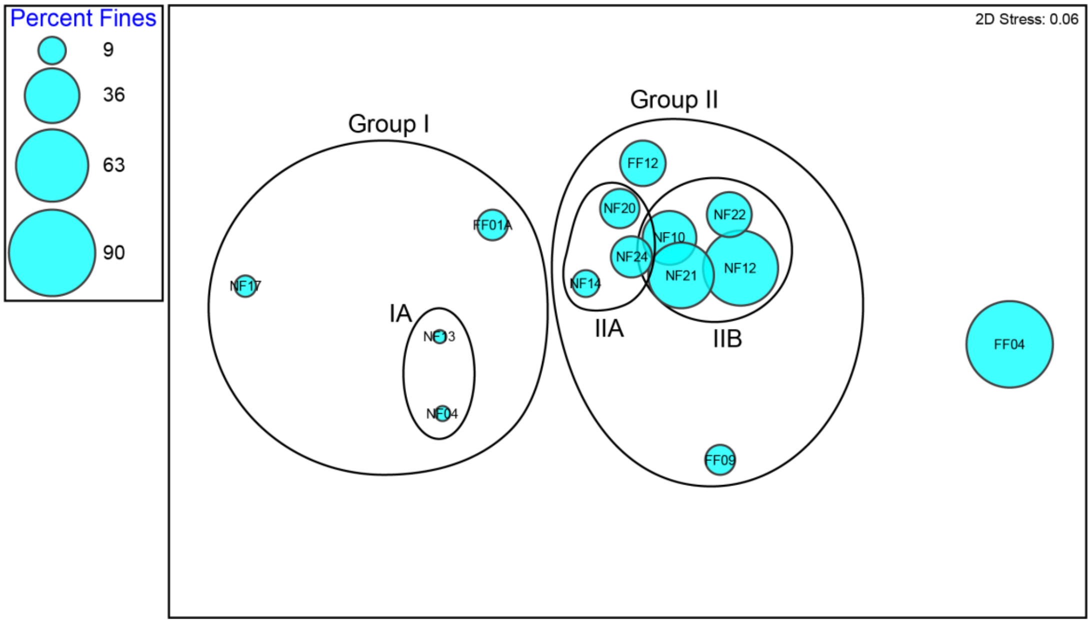


**Figure 3-19. Percent fine sediments superimposed on the MDS ordination plot of the 2017 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. The ordination and cluster analysis are both based on Bray-Curtis Similarity.**

**Table 3-5. Abundance (mean # per grab) of numerically dominant taxa (10 most abundant per group) composing infaunal assemblages identified by cluster analysis of the 2017 samples.**

| Family | Species | Group I | | | Group II | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | NF17 | IA | FF01A | FF12 | IIA | IIB | FF09 | FF04 |
| **Nemertea** | | | | | | | | | |
| Tubulanidae | Nemertea sp. 12 | 1.0 | 4.5 | - | 28.0 | 18.3 | 28.0 | 39.0 | 9.0 |
| | *Tubulanus pellucidus* | - | - | - | - | - | 0.3 | 2.0 | 10.0 |
| **Mollusca (Bivalvia)** | | | | | | | | | |
| Cardiidae | *Parvicardium pinnulatum* | 6.0 | 16.0 | 46.0 | 6.0 | 2.3 | - | 2.0 | - |
| Mytilidae | *Crenella decussata* | - | 3.5 | - | - | 1.3 | - | 51.0 | - |
| Nuculidae | *Nucula delphinodonta* | - | 27.5 | 25.0 | 23.0 | 16.3 | 9.3 | 111.0 | 4.0 |
| Pharidae | *Ensis leei* | 24.0 | 13.0 | 2.0 | 4.0 | 0.7 | - | - | - |
| Thyasiridae | *Thyasira gouldi* | - | - | - | - | 0.3 | 2.3 | 33.0 | 5.0 |
| **Annelida (Polychaeta)** | | | | | | | | | |
| Ampharetidae | *Anobothrus gracilis* | - | 0.5 | 1.0 | 4.0 | 2.0 | 3.5 | 206.0 | 62.0 |
| Apistobranchidae | *Apistobranchus typicus* | - | - | 2.0 | - | 0.7 | 6.5 | 1.0 | 22.0 |
| Capitellidae | *Mediomastus californiensis* | 3.0 | 31.0 | 81.0 | 197.0 | 318.7 | 323.0 | 41.0 | 33.0 |
| Cirratulidae | *Chaetozone anasimus* | 23.0 | 32.5 | 5.0 | - | - | - | 1.0 | 83.0 |
| | *Kirkegaardia baptisteae* | 3.0 | 4.5 | 105.0 | 363.0 | 129.7 | 144.3 | - | - |
| | *Kirkegaardia hampsoni* | 1.0 | 2.0 | 45.0 | 124.0 | 53.0 | 59.3 | - | - |
| | *Tharyx acutus* | 11.0 | 194.5 | 101.0 | 441.0 | 304.7 | 212.8 | 47.0 | - |
| Cossuridae | *Cossura longocirrata* | - | 0.5 | - | - | - | 7.0 | 4.0 | 90.0 |
| Dorvilleidae | *Parougia caeca* | 18.0 | 3.5 | - | 10.0 | 17.7 | 33.8 | 2.0 | 3.0 |
| Lumbrineridae | *Ninoe nigripes* | - | - | 9.0 | 61.0 | 40.7 | 61.3 | 37.0 | 21.0 |
| | *Scoletoma hebes* | - | 1.0 | - | 57.0 | 59.3 | 20.0 | - | - |
| Maldanidae | *Euclymene collaris* | 21.0 | 113.5 | 1.0 | - | - | 1.8 | - | - |
| Nephtyidae | *Aglaophamus circinata* | 6.0 | 39.5 | 12.0 | 1.0 | 3.3 | - | 5.0 | - |
| Orbiniidae | *Leitoscoloplos acutus* | 1.0 | 0.5 | 3.0 | 17.0 | 20.0 | 67.3 | 9.0 | 7.0 |
| Paraonidae | *Aricidea catherinae* | 9.0 | 264.5 | 47.0 | 639.0 | 617.3 | 142.0 | - | - |
| | *Aricidea quadrilobata* | - | - | - | 1.0 | 1.7 | 20.5 | 26.0 | 42.0 |
| | *Levinsenia gracilis* | - | 3.0 | 33.0 | 178.0 | 121.7 | 134.0 | 117.0 | 250.0 |
| Polygordiidae | *Polygordius jouinae* | 86.0 | 54.5 | 118.0 | 13.0 | 29.7 | 4.3 | 7.0 | 1.0 |
| Sabellidae | *Euchone incolor* | - | 2.5 | 17.0 | 18.0 | 24.0 | 22.8 | 3.0 | 16.0 |
| Spionidae | *Polydora cornuta* | 1.0 | - | - | 215.0 | 0.7 | - | - | - |
| | *Prionospio steenstrupi* | 4.0 | 8.5 | 38.0 | 81.0 | 214.0 | 58.8 | 61.0 | 3.0 |
| | *Spiophanes bombyx* | 314.0 | 42.5 | 106.0 | 52.0 | 165.0 | 10.5 | 3.0 | - |
| Syllidae | *Exogone hebes* | 48.0 | 164.0 | 49.0 | - | 62.0 | 7.8 | 14.0 | - |
| | *Sphaerosyllis erinaceus* | 29.0 | - | 7.0 | - | 0.3 | - | 2.0 | - |
| **Annelida (Oligochaeta)** | | | | | | | | | |
| Enchytraeidae | *Grania longiducta* | 11.0 | 1.0 | - | - | - | - | - | - |
| Tubificidae | *Peosidrilus coeloprostatus* | 63.0 | - | - | - | - | 0.3 | - | - |

### 3.3 Sediment Profile Imaging

Starting in 1992, Sediment Profile Images (SPI) were collected at a set of unconsolidated sediment stations to gather baseline data around the nearfield region where the MWRA offshore outfall would be located (Figure 2-2). The primary objective was to collect data on benthic habitat conditions for infaunal communities and to measure the depth of the apparent color redox potential discontinuity (aRPD) layer as described in the MWRA's Contingency Plan (MWRA 2001). During baseline monitoring, SPI data were collected in six years, in August of 1992 and 1995, and annually from 1997 to 2000. In 2001 the offshore outfall went into operation and annual August SPI data collection continued to document post-diversion conditions in the nearfield region.

The region around the outfall has a complex bottom topography related to the presence of submerged drumlins, geological features produced by glacial drift deposits. Much of the bottom is covered with large boulders with limited areas consisting of unconsolidated pebble to silt-clay sediments (Butman et at. 1992, Nestler et al. 2017). The drumlin tops are at about 25 m depth and the bottoms at 30 to 40 m with nearfield SPI stations ranging in depth from 21 to 37 m. This topography is a major factor controlling wave-bottom stress, bottom stability, sediment transport, and the distribution of sediment types (Butman et al. 2008, Warner et al. 2008).

Comparisons of baseline habitat conditions between 1992 and 2000 with post-baseline outfall operation conditions from 2001 to 2017 have not identified any changes in benthic habitat quality related to outfall operation (Table 3-6). Those changes that have occurred appeared to be regional and not associated with outfall operation. The current dominance of physical processes in the nearfield is the principle reason that after 16 years of operation there continues to be no evidence of an outfall effect on benthic habitat quality. Had outfall operation affected benthic communities and habitat quality it would be expected that species diversity and richness would decline, opportunistic species and total abundance would increase, and apparent color redox-potential discontinuity (aRPD) layer depth would become shallower (Maurer et al. 1993, Puente and Diaz 2015). None of these happened. Post-diversion species diversity and richness increased, opportunistic species did not increase, total abundance declined, and aRPD layer depth increased (Nestler et al. 2017).

In contrast to predicted impacts from ocean outfalls, baseline to post-baseline comparisons showed significant increases in aRPD layer depth (ANCOVA of baseline period and three post-baseline periods with year as covariate, Model df = 7, $F = 49.0$, $p = <0.001$) but there was no significant change in the Organism Sediment Index (OSI), a measure of benthic habitat quality (Rhoads and Germano 1986), across the 23 nearfield stations. Baseline years had significantly shallower aRPD depth than any of the post-baseline year periods and the period from 2013 to 2017 had the deepest aRPD layers. Patterns in standardized aRPD layer depth (mean centered and unit variance) pointed to a gradual deepening from shallowest in the late 1990s with a sharp deepening starting in 2012. The annual average aRPD layer depth for 2017 continued to be among the highest for all the post outfall years extending the aRPD deepening trend that started in 2004 (Table 3-6 and Figure 3-20).

**Table 3-6. Summary of SPI parameters baseline and post-diversion years for all nearfield stations.**

| | Baseline Years 1992-2000 9-Year Interval | Post-Diversion Years 2001-2017 16-Year Interval | Only 2017 |
|---|---|---|---|
| **SS** | Advanced from I to II-III | Bimodal: II-III tending to I | Bimodal: I-II and I |
| **OSI - Low** | 4.8 (1997) | 5.8 (2003) | |
| **OSI - High** | 7.2 (2000) | 8.7 (2012) | 8.0 (N = 21) |
| **RPD - Low** | 1.8 cm (1997 and 1998) | 2.1 cm (2003) | |
| **RPD -High** | 3.0 cm (1995) | 5.5 cm (2015) | |
| **Annual Mean RPD Measured** | 2.2 (0.48 SD) cm | 3.6 (1.05 SD) cm | 4.4 (1.14 SD) cm N = 14 |
| **Annual Mean RPD All Values** | 2.4 (0.47 SD) cm | 3.2 (0.87 SD) cm | 4.2 (1.33 SD) cm N = 23 |

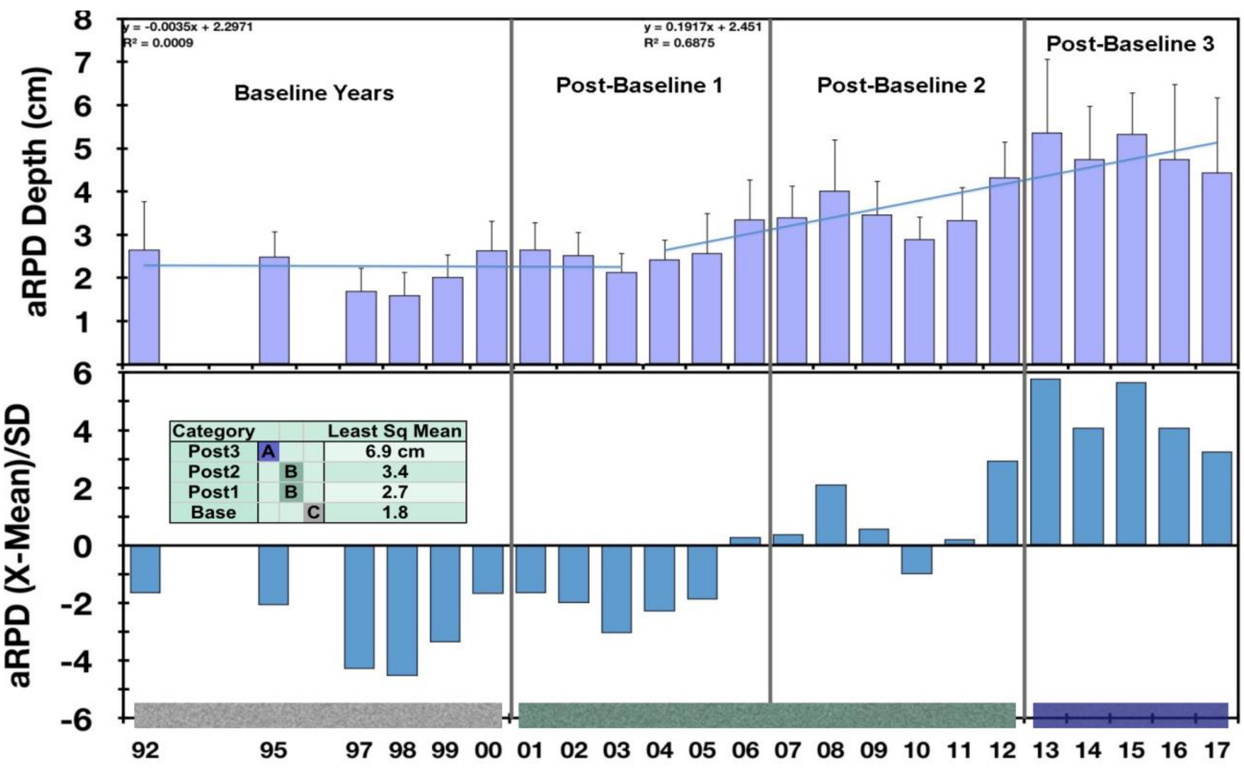


**Figure 3-20. Upper panel is average annual aRPD layer depth for nearfield stations with measured aRPD layers. Bars are one standard deviation. Lines are based on breakpoint linear regression. Data were broken into four approximately equal groups of sampling years for comparison through time. Table insert is the Tukey's HSD multiple mean test results. Lower panel is pattern of standardized (mean centered and unit variance) aRPD layer depths.**

Being among the highest annual averages for post outfall monitoring, the grand mean aRPD layer depth in 2017 did not exceed the threshold of a 50% decrease from the baseline conditions. If only measured values are considered the thickness of the aRPD for 2017 would be 4.4 cm (SD = 1.14 cm, 14 stations in mean). At 9 of the 23 stations, the aRPD was deeper than prism penetration. This was due to coarse grain size and high sediment compaction that limited prism penetration, but as Janssen et al. (2005) found, the apparent high levels of porewater circulation driven by current or wave action that pumps oxygenated water in coarser sediments may also be a factor. From the start of SPI monitoring in 1992 to 2003 the thickness of the annual mean aRPD layer remained unchanged with a grand average of 2.2 cm (breakpoint linear regression $R^2 = <0.01$). From 2004 to 2017 the aRPD layer depth was variable but trended deeper by about 0.2 cm per year (breakpoint linear regression $R^2 = 0.69$) (Figure 3-20).

The general nearfield pattern of increasing aRPD depth with time was observed at the five stations with fine-sand-silt-clay sediments (NF08, NF12, NF21, NF22, and NF24) where aRPD layers were measurable almost every year. For example, station NF24 located about 0.4 km from the south-west end of the outfall followed the general nearfield pattern with deepest aRPD layers from 2012 to 2017 (Figure 3-21). Patterns of aRPD depth have generally been consistent among these five stations within each year suggesting that the factors responsible for the depth of the aRPD layer in the nearfield were regional in scale. The deepening of the aRPD layer is an indication of continuing high quality benthic habitat conditions over the entire nearfield region. High diversity of benthos also confirms the presence of high quality benthic habitat (Section 3.2). Had outfall operation degraded benthic habitat quality both aRPD layer depth and diversity would had declined, as has been observed at other ocean outfalls (Puente and Diaz 2015).

Post-diversion changes that have occurred were closely related to major physical disturbance events such as storms and appeared to affect the entire nearfield region. The structure of surficial sediments appeared to be related primarily to the intensity and number of major storm events, and secondarily to the timing of storms prior to the annual August SPI sampling. Butman et al. (2008) ranked storms occurring in Massachusetts Bay from 1990 to 2006 by wind stress and wave-generated bottom stress. A storm was defined based on bottom-wave stress at a water depth of 30 m as a period when the bottom stress caused by waves was greater than 0.1 Pascal (Pa) for at least 6 hours. Their integrated excess bottom stress caused by waves (IWAVE) calculations for 30 m depth (the approximate depth of nearfield stations) were summarized and compared to processes structuring surficial sediments derived from SPI (Figure 3-22).

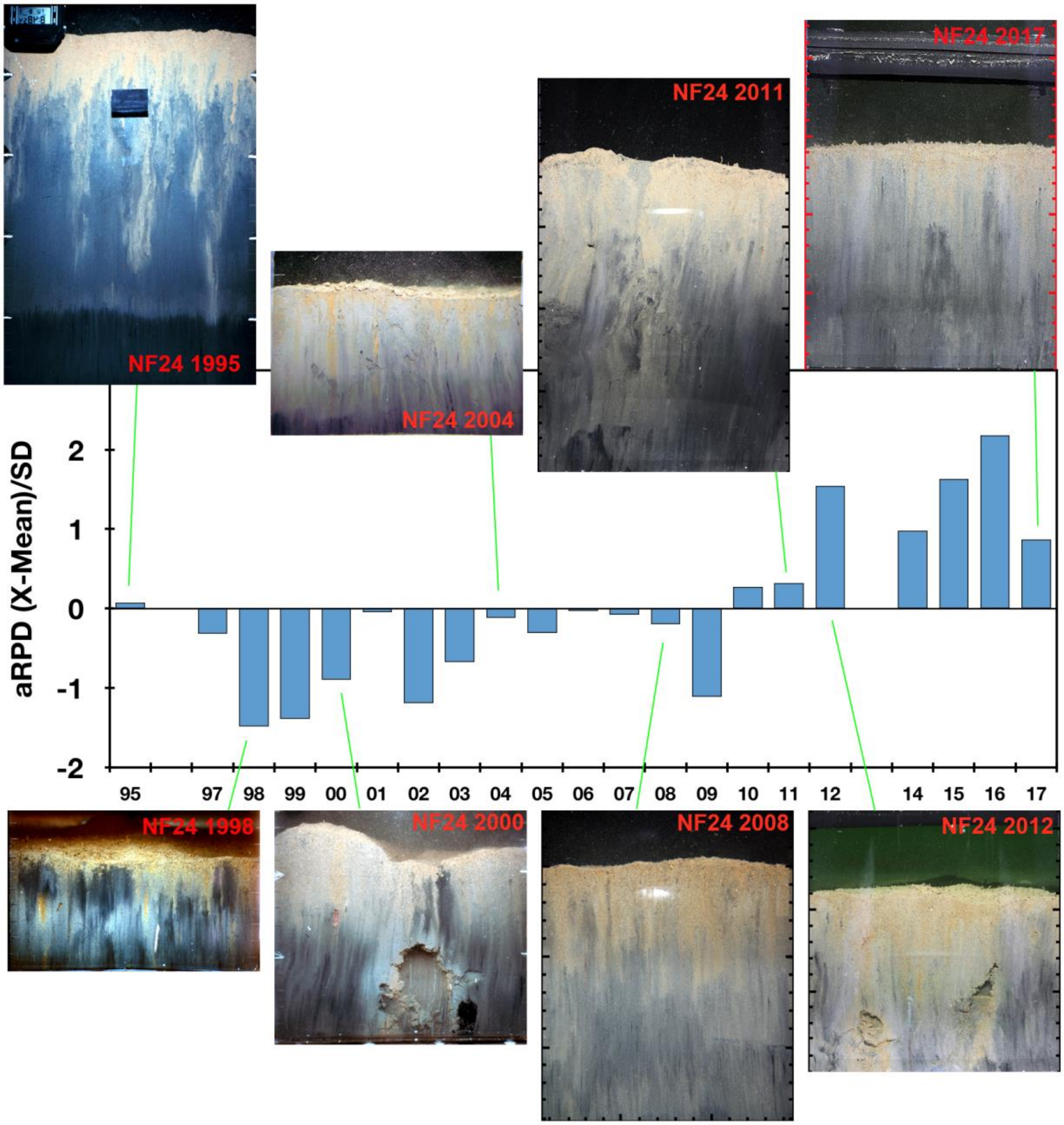


**Figure 3-21. Standardized (mean centered and unit variance) deviation of aRPD layer depth at nearfield station NF24 with example images. Grand mean for all years at NF24 was 2.7 cm (SD = 1.03 cm). Scale on side of images is in cm.**

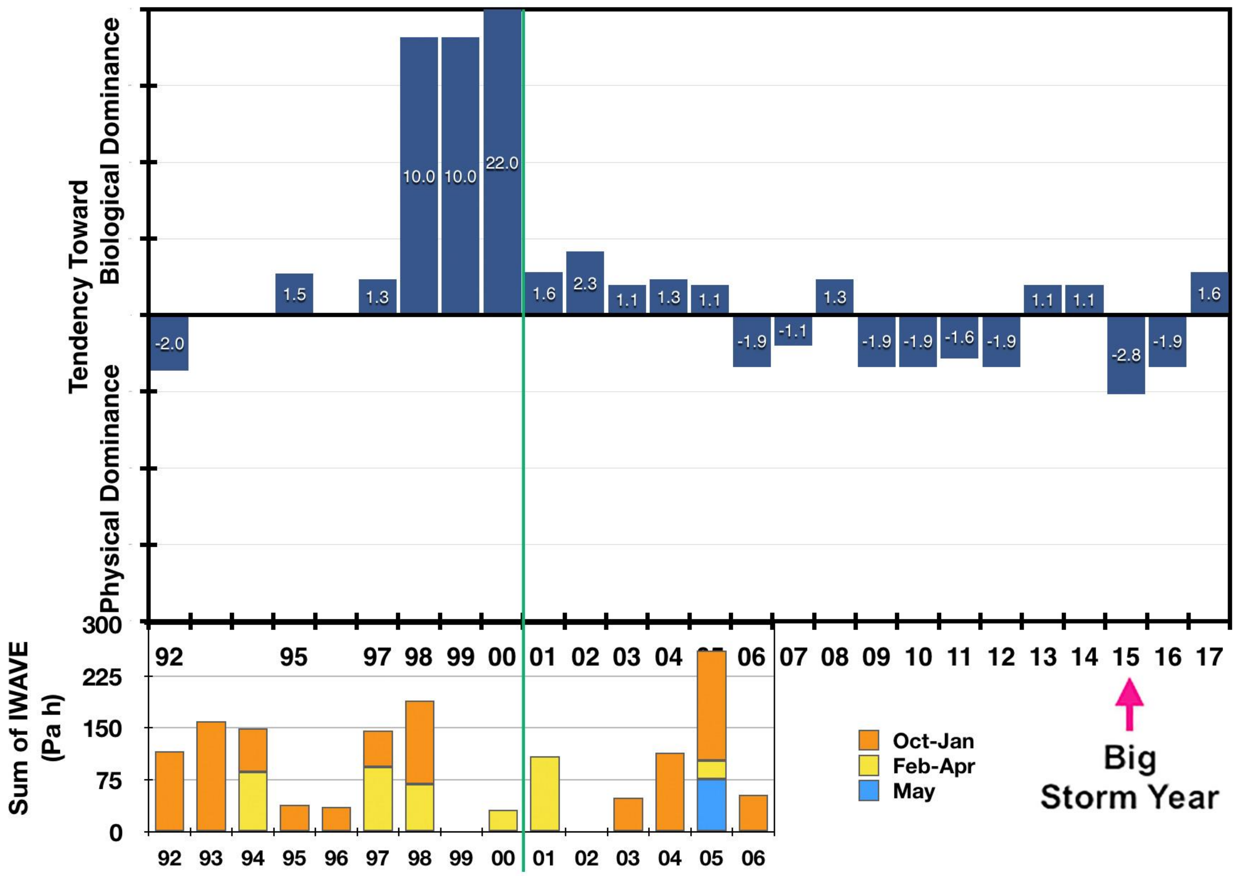


**Figure 3-22. Odds of biological verses physical processes dominance of surface sediments for nearfield stations from 1992 to 2017 (dark blue bars). Storm intensity (as measured by integrated bottom-wave stress, IWAVE) and timing are from Butman et al. (2008). Storms are binned by seasonal occurrence prior to the annual August SPI sampling. SPI were not collected in 1993-4 or 1996. Vertical green line marks the start of outfall operation.**

The odds of the sediment surface being physically dominated significantly increased with storm intensity (Logistic Regression, df = 1, ChiSq = 5.09, p = 0.024). For every 10 Pascal hour (Pa h) increase in storm intensity the odds of physical dominance increased by 0.06. The influence of these storms on benthic species that live on or at the sediment surface was also apparent. While not significant, there was a tendency for lower amphipod and isopod abundance in years with higher storm intensities (Figure 3-23). The two lowest amphipod and isopod abundance years were associated with the highest cumulative IWAVE year in 2005 and the following moderate IWAVE year. The impact of storms in 2005 seemed to have lasted into 2006 but by 2007 amphipod and isopod abundance increased by a factor of four.

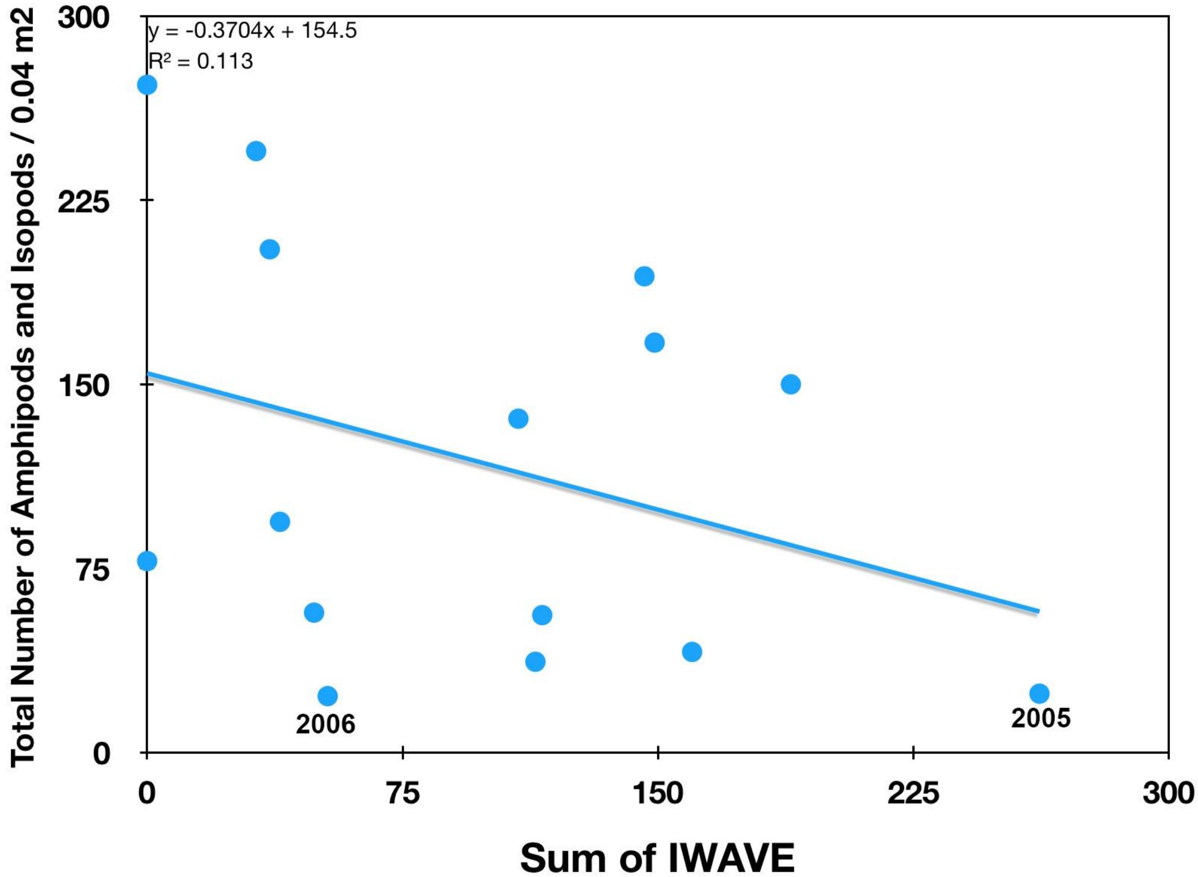


**Figure 3-23. Relationship between storm intensity (IWAVE from Butman et al. 2008) and total abundance of amphipods and isopods for all sampled nearfield stations from 1992 to 2006.**

The highest bottom stress winter on record was the October 1991 "perfect storm" (Butman et al. 2008) that occurred nine months prior to initiation of SPI sampling in August 1992. At that time much of the nearfield was colonized by pioneering successional stage I species, which was a benthic community response consistent with a major disturbance event (McCall 1977, Harris 2014). Large numbers of tubes of spionid polychaetes assemblages were present at 19 of 20 nearfield stations in August 1992 with five stations having assemblages of spionids dense enough to form tube mats (Blake et al. 1993). Mat densities are defined as >5 tubes per linear cm of image or >50,000 tubes per $m^2$. Polychaete tube mats were also observed in the nearfield in July 1984 and August 1987 SPI surveys conducted prior to start of MWRA monitoring, but not in winter SPI surveys of those years (Shea et al. 1991). Shea et al. (1991) found that polychaete tube mats developed in the summer. After summer peaks in benthic populations, mats were broken down with the onset of winter with declining temperature and increased storm activity. Over the baseline period (1992 to 2000) the occurrence of polychaete tube mats was sporadic. In 1992, 5 of 20 stations had tube mats; no mats were observed in 1995, 1997 or 1998; in 1999, 9 of 23 stations had mats (Figure 3-24); and none again in 2000. A scarcity of mats continued into the post-diversion period with mat densities of polychaetes observed at 4 of 23 stations in 2001 and then none until a mat appeared at one station (NF16) in 2014. No tube mats were observed in 2015 through 2017 SPI. It also appeared that the species forming the tube mats differed from year to year.  For example, distinctive medium-size twisted tubes were widespread at nearfield stations only from 2001 to 2003 (Figure 3-24).

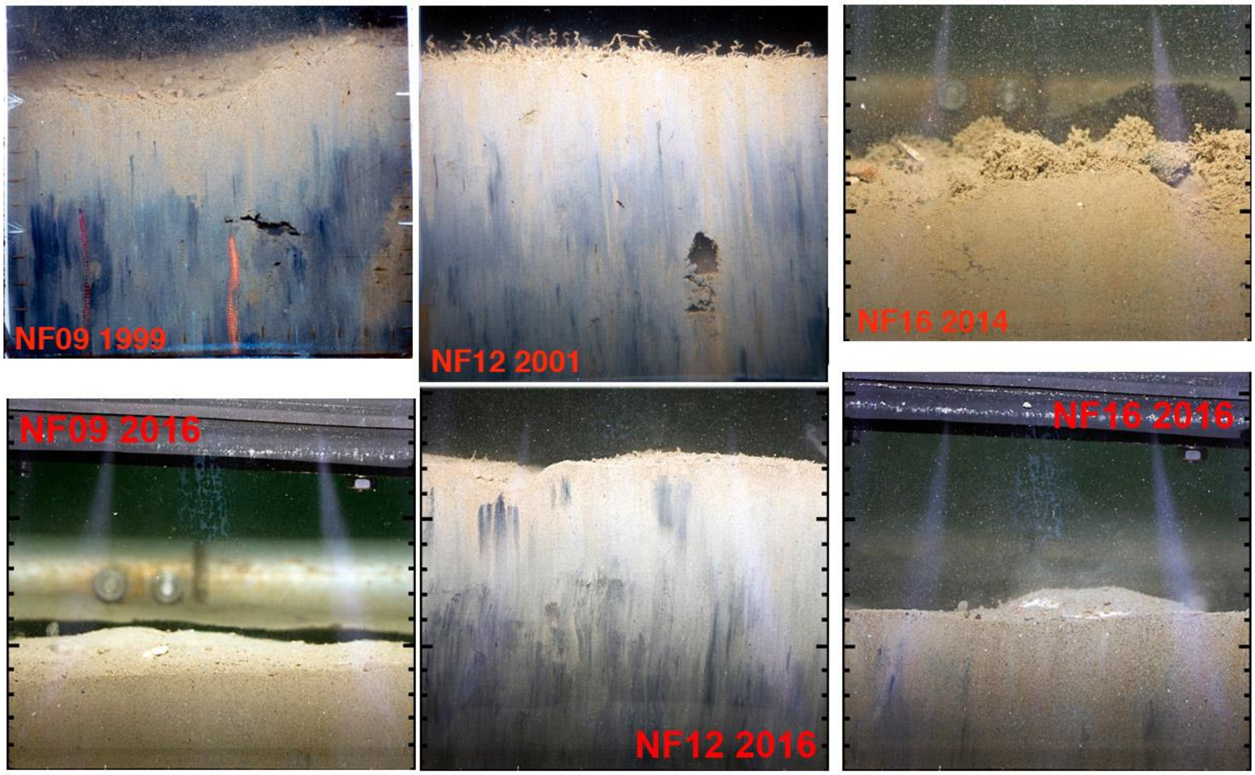


**Figure 3-24. Tube mats on sediment surface pre- and post-diversion.  Species of tube builders appeared to change through time.  1999 mats are likely similar to tube mats observed in 1992 images and represent the Stage I pioneering species.  Medium-size twisted tube at NF12 were widespread at nearfield stations only in 2001 and 2002.  Deeper dwelling species and biogenic structures that represent Stage III species can be seen at NF09 in 1999 and NF12 in 2001.  In 2016 and 2017 surface sediments at these stations tended to be more physically dominated.  1992 images were not available.  Scale on side of images is in cm.**

At the start of SPI monitoring in 1992, and perhaps even before in the late 1980s, it appeared that storm related disturbances may have kept nearfield benthos in an early successional state with a predominance of physical processes structuring surficial sediments (odds of physical dominance in 1992 was 2:1 based on one image from each station).  Surficial sediments dominated by physical processes would have relatively featureless sediment surface or show evidence of ripples caused by currents.  Biologically dominated sediments would have biogenic features such as feeding mounds or pits, and large tubes and burrows.  The dominance of physical processes at the start of the nearfield SPI monitoring was coincident with two of the largest storms recorded for Massachusetts Bay (Butman et al. 2008).  These were the October 1991 Perfect Storm and the Blizzard of 1992 in December 1992.

Biological processes dominated in 1990 through 2000 even though 1998 was a high integrated wave stress (IWAVE) year, whereas 1999 and 2000 were both low IWAVE years. The odds in favor of surface sediments being biologically dominated was 10:1 to 22:1 from 1998 to 2000 (Figure 3-22). In 2000 only station NF02 had a physically dominated surface, all other nearfield stations had varying degrees of biological dominance. In 2001, following the start of outfall operation, strong spring storms were associated with a steep decline in biological processes with the odds dropping to less than 2:1 (Figure 3-22).

The dominance of physical processes which started in 2001 was a shift away from the dominance of surficial biogenic structures such as feeding pits and mounds. For example, in 1998 surficial sediments at station FF13 were biologically dominated, from 1999 to 2001 a combination of physical and biological processes dominated, and from 2002 to 2017 physical processes dominated (Figure 3-25). From 2001 to 2014 surface sediments at nearfield stations tended to be dominated by a combination of biological and physical processes. In 2015 the odds shifted to about 3:1 in favor of physical dominance, likely related to the previous winter’s storms. A combination of biological and physical processes dominated the structuring of surfical sediments in 2017 pointing to a trend of increasing biological dominance that started in 2016, a year after a series of strong storms occurred (Rocky Geyer, personal communication). In 2017, sediments remained primarily physically dominated, though the odds of biological dominance increased to 1.6:1 (Figure 3-22).

The importance of biological processes continued to decline through time across the nearfield region. Fine-medium-sand station NF05 provides a good example of this trend (Figure 3-26). The diversity of tube types and sizes remained high from 1995 to 2002. By 2005 tubes were smaller and declined in density as did other biogenic features, such as infaunal and oxic feeding voids, which led to a lowering of estimated successional stage by the early 2010s (Figure 3-27). Not all nearfield stations changed as much through time. At most fine-sand-silt-clay stations a combination of biological and physical processes consistently dominated after 2000, with fewer biogenic structures. Benthic habitat conditions at stations NF08, NF12 (Figure 3-28), NF21, and NF22 have remained the most consistent from 1998 to 2017.

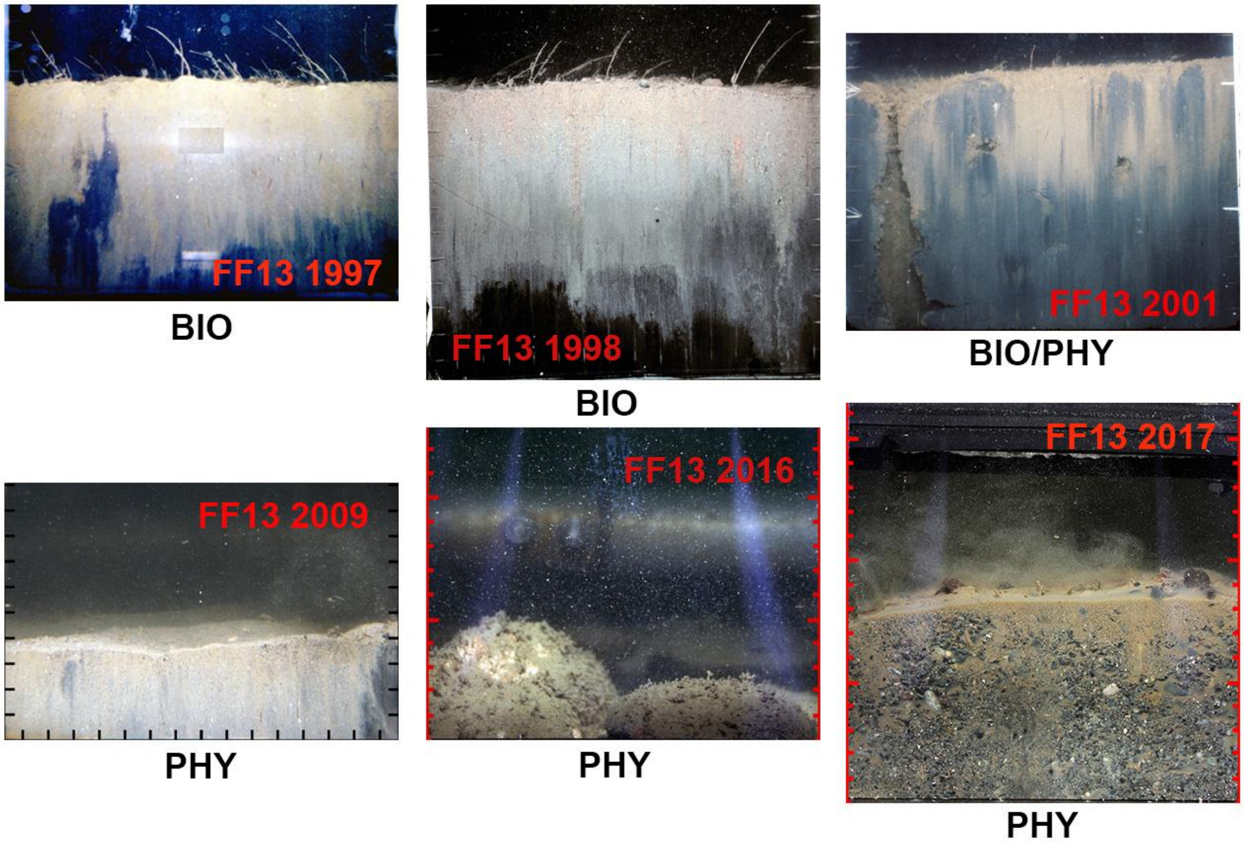


**Figure 3-25. Shift in dominance of processes structuring surface sediments at station FF13 through time. BIO = biological dominance, BIO/PHY = combination of biological and physical dominance, PHY = physical dominance. Scale on side of images is in cm.**

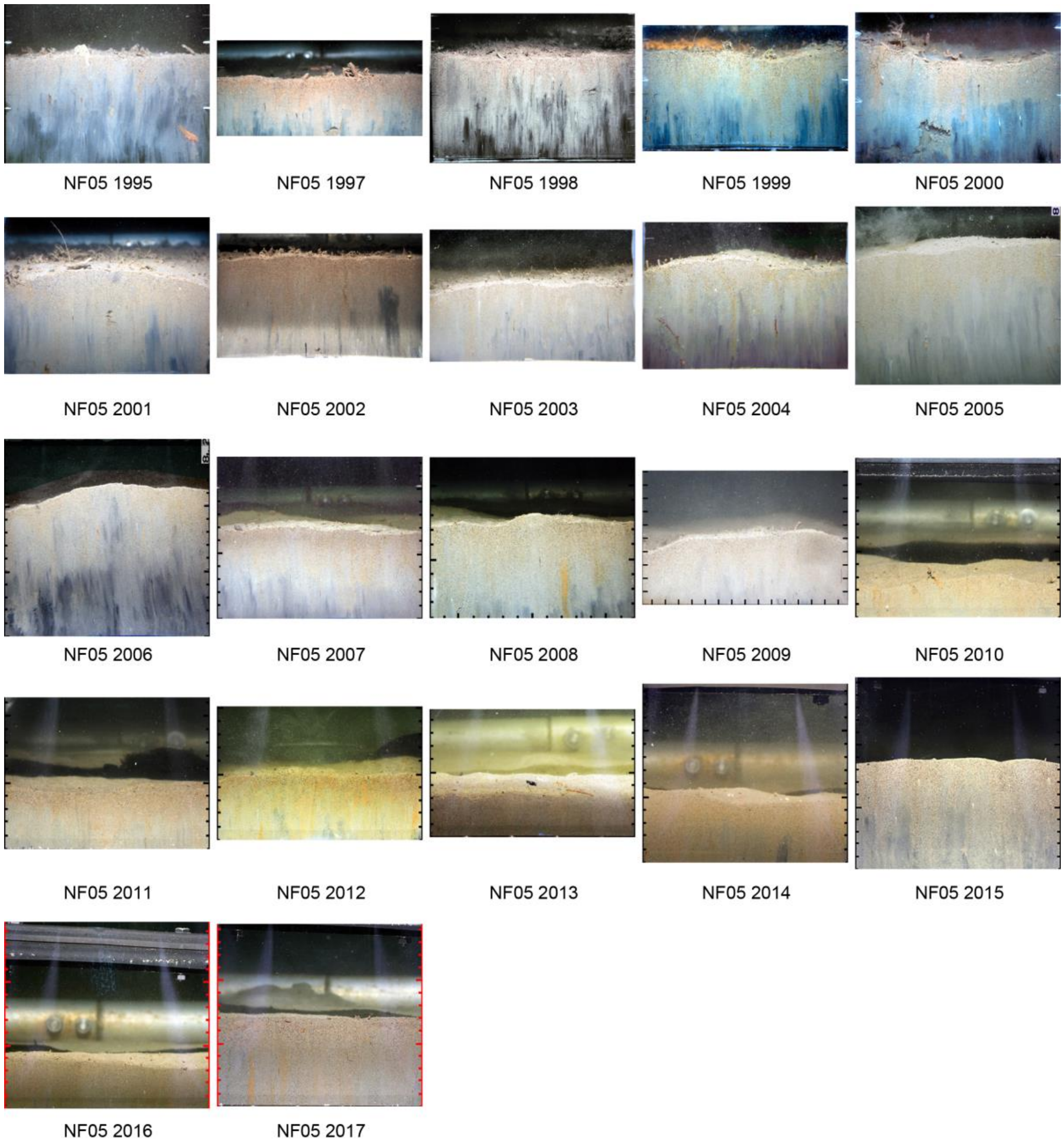


**Figure 3-26. Mosaic of SPI images for station NF05 where surface sediments were increasingly dominated by physical processes through time. Scale on side of images is in cm.**

| Stat. | 1992 | 1995 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | Modal Grain-Size | Distance from Outfall (Km) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FF13 | | | I-II | II-III | II | I-II | II-III | I | I | I-II | I | I | I | I | I-II | I | I-II | I | I | I | I | I | I | FSSIGRPB | 7.5 |
| NF18 | I | I | I-III | I-II | II | II | I-II | I-II | I-II | I-II | I | I-II | I | I | I | I | I | I | I | I | I-II | I | I-II | FSSIGRPB | 2.1 |
| NF20 | I | I | I | II-III | II | I-II | I-II | I-II | I | I | I-II | I | I | I-II | I | I | I-II | I | I | I | I | I | I | FSSIGRPB | 3.6 |
| FF10 | I-III | | I | II-III | II | I | I-II | I-III | I-II | I-III | I-II | I | I | II-III | I | I | I | I | I | I | I-II | I | I-II | FSMSGR | 7.1 |
| NF14 | I | I | I | II-III | II-III | II | I-II | I | I-II | I-II | I | I | I | I | I | I | I | I | I | I-III | I | I-II | I | FSMSGR | 1.6 |
| NF15 | I | I | I | II-III | II | II | I-III | I-II | I-II | I-II | I-II | I | I | I | I | I | I | I | I | I | I-II | I-II | I | FSMSGR | 2.9 |
| NF23 | | I | I | II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I | I | I | I | I | I-II | FSMSPB | 1.5 |
| NF04 | I | I-II | I-II | II | II | I-II | I-II | I | I | I | I | I-II | I | I-II | I-II | I-II | I-II | I-II | I | I | I | I | II-III | FSMS | 3.4 |
| NF05 | I | I-II | I-III | II-III | II | II-III | II-III | II-III | II-III | II-III | I-II | II-III | II-III | I-II | II-III | I-II | II-III | I-II | I | I | I | I | I-II | FSMS | 5.4 |
| NF13 | I | I | I | II | II | I-II | I-II | I-II | I-II | I-II | I-II | I | I | I | I | I | I | I-II | I | I | I | I-II | II | FSMS | 1.7 |
| NF17 | I | I | I | II | II | I-II | I-II | I-II | I-II | I-II | I | I-II | I | I-II | I-II | I | I-II | I | I | I | I | I | II-III | FSMS | 1.0 |
| NF19 | | I | I-II | I-II | II | II | I-II | I | I | I | I | I | I | I | I | I | I | I-II | I | I | I-II | I-II | I | FSMS | 1.4 |
| FF12 | | | I | II-III | II-III | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I-II | I | I | I | I | I-II | FS | 8.1 |
| NF07 | I-III | I | I | II-III | II-III | II-III | II-III | II | II | I-II | I-II | I-II | I-II | II-III | I-II | I-II | I-II | I-II | I | I | I-II | I-II | I-II | FS | 3.0 |
| NF09 | I-III | I-III | I | II-III | III | III | II-III | II-III | II-III | II-III | I-III | II-III | II-III | II-III | II-III | I-II | II-III | II-III | I | I | I-II | I-II | I-II | FS | 3.9 |
| NF10 | I | I-III | I-II | II-III | III | III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | I-II | II-III | I-II | II-III | II-III | I-III | I | I | I-II | I | FS | 3.0 |
| NF02 | I | I | I-III | | | I | I-II | I-II | I-II | II-III | II-III | I | I | I | I | I | I | I | I | I | I-II | I-III | I | FSSI | 5.6 |
| NF16 | I | II-III | I | II-III | II-III | II-III | II-III | II-III | II-III | II-III | I-III | I | I | I | I | I-II | I | I-III | I-III | I | I | I | I-II | FSSI | 2.9 |
| NF08 | I-III | I | I-II | II-III | II | II | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | I-III | I-III | I-III | I-II | I | FSSICL | 5.3 |
| NF12 | II-III | I-III | I-III | II-III | III | III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | I-III | II-III | II-III | I-III | I-III | I-II | I-III | I-III | FSSICL | 2.4 |
| NF21 | | II-III | I | II-III | II-III | III | III | III | III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | I | I-III | I | I-III | I-III | FSSICL | 3.5 |
| NF22 | | I-III | I-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | II-III | III | II-III | II-III | I | I | I | I-II | I | FSSICL | 4.2 |
| NF24 | | I | I-III | II-III | II-III | II-III | II-III | I-II | II-III | II-III | II-III | I-II | I | I-II | II-III | II-III | II-III | II-III | I | I-II | I | I-II | II | FSSICL | 0.4 |

**Figure 3-27. Estimated successional stage from nearfield SPI stations arranged from coarsest to finest sediment grain-size. Stage I is representative of a pioneering or opportunistic fauna, Stage II represents intermediate fauna, and Stage III is representative of equilibrium fauna. Combinations of Stages represent the presence of more than one successional stage. Sediment descriptors are: CL - clay, FS - fine-sand, GR - gravel, MS - medium-sand, PB - pebble, SI - silt. Vertical line separates baseline from post-diversion years.**

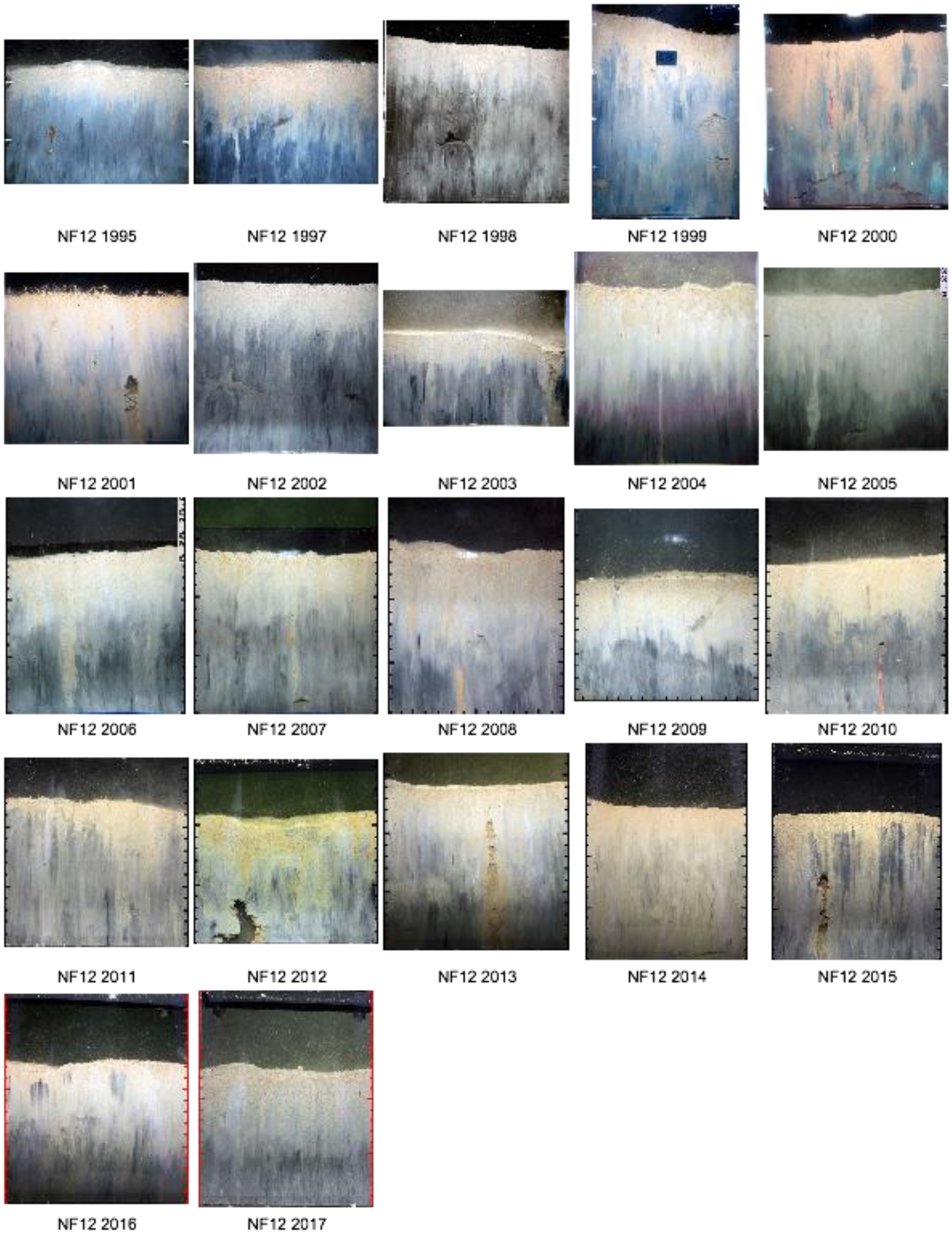


**Figure 3-28. Mosaic of SPI images for station NF12 that had little temporal variation in grain-size. Scale on side of images is in cm.**

Sediments continued to be heterogeneous in 2017 ranging from fine-sand-silt-clay to cobble. Variation in grain-size had two components, small-scale heterogeneity within a station and large-scale regional trends. Both sources of variation were at play for baseline and post-diversion years. Year to year, individual stations varied little in modal grain-size patterns. For example, within station variation was consistently high at station FF10 (Figure 3-29) and low at station NF12 (Figure 3-28). Sediments appeared to change the most after periods with severe storms. Unfortunately there were no data to assess the effects of the October 1991 "perfect storm," but a May 2005 severe storm that had the second highest bottom stress on record (Butman et al. 2008) did coincide with a general coarsening of modal grain-size in August 2005. In 2004 the grand average modal Phi for all nearfield stations was 4.4 and in 2005 it was 4.1. This is equivalent to the average nearfield grain-size coarsening from very-fine-silty-sand to very-fine-sand. For example, sediments at station FF13 changed from fine-sand-silt sediments in 2004 to coarse pebble/cobble in 2005 and remaining so until 2008 when finer sediments occurred. Overall, 9 of 23 stations coarsened from 2004 to 2005 with pebbles more numerous in 2005 relative to 2004. Grain-size analysis also found coarsening of sediments between 2004 and 2005. For example, station NF12 went from 15% to 26% sand with increased medium-sand and fine-sand fractions. While total percent sand at Station NF17 was similar between 2004 (96%) and 2005 (98%) there was substantial coarsening. Fine sand decreased by more than half, from 56% of the sediments to 25%. Simultaneously, coarse and very coarse sand each increased at the site from <5% of the sample in 2004 to 12% and 17% respectively in 2005. The coarsening of modal grain-size in 2005 was consistent with the higher bottom stress in 2005 from storms (Butman et al. 2008, Warner et al. 2008).

In contrast to years between 2006 and 2014 when within station variation in sediment grain-size was low, 2015 was a year of change. At 5 of 23 nearfield stations (FF12, NF02, NF07, NF10, and NF17) sediments appeared to be sandier and coarser in 2015 relative to 2014. For example, modal grain-size at NF02 went from fine-sand-silt in 2014 to fine-medium-sand in 2015 (Figure 3-30). The overall slightly sandier appearance of sediments in 2015 is consistent with the stormy winter of 2014-2015 (R. Geyer, personal communication). Strong northeasters in October and February, a northwester in March, and a late northeaster in June all mixed the water column to depths greater than the nearfield stations and could have affected surficial sediments by redistributing fine-grained sediments. By August 2016, the coarser grained sands that occurred in 2015 at stations FF12, NF02, NF07, and NF10 had returned to 2014 estimates. By 2017, NF17 returned to previous year's estimates and NF02 became slightly coarse again. Modal grain-size at NF17 went from fine-medium-sand in 2014 to medium-sand in 2015 and 2016, and back to fine-medium-sand in 2017 (Figure 3-30). Three of these stations were sampled for grain-size analysis. Station FF12 exhibited a pattern of decline in percent fines from 2014 to 2015 and an increase in 2016, as did station NF10. At station NF17 percent fines were about the same from 2014 to 2016 (Table 3-7). Overall, grain-size analysis indicated the average percent fines (silt+clay) at the 11 nearfield stations sampled did not vary more than 4% in the last four years, and was 24% in 2014, 22% in 2015, 26% in 2016, and 24% in 2017 (Section 3.1).

During the baseline period mean aRPD layer depth, including stations where aRPD was deeper than prism penetration, varied from a low of 1.8 cm (SE = 0.13 to 0.14) in 1997 and 1998 to a high of 3.0 cm (SE = 0.22) in 1995 (Table 3-6). The largest deepening of the aRPD layer between successive samplings was 0.5 cm from 1998 to 1999 and appeared associated with an increase in the levels of biogenic activity. The increase in both successional Stage II and Stage III fauna at fine-grained stations in 1998 and 1999 was a key factor in the deepening of the aRPD (Figure 3-27). Most of the biogenic activity was related to burrowing organisms that created feeding mounds and pits in the sediment surface, subsurface feeding voids, and small tube-building worms. Stage II and Stage III fauna were primarily related to the modal sediment grain-size of fine-sand-silt-clay that had the highest organic matter content of nearfield stations and is known to support a high diversity of bioturbating benthos (Rosenberg 2001).

Biogenic structures associated with Stage III fauna were abundant (about 7 per image) from 1998 to 2004 with no trend in the annual median number (breakpoint linear regression $R^2 = 0.007$, $p = 0.858$). Starting in 2005 biogenic structures declined (breakpoint linear regression $R^2 = 0.42$, $p = 0.018$). This decline was coincident with major winter 2004-2005 and late spring 2005 storms that combined produced the highest cumulative bottom energy for the nearfield region between 1991 and 2006 (Figure 3-22) (Butman et al. 2008). Biogenic structures remained low from 2005 through 2017 at about 2 per image, even at fine-sand-silt-clay stations (Figure 3-31). By 2013, evidence of Stage III fauna in SPI declined to a level similar to that found at the start of nearfield monitoring in 1992 (Figure 3-27). In 2016 and 2017, after a stormy 2015 (Rocky Geyer, personal communication), successional stage advanced with evidence of Stage II and III fauna at about half of the stations. However, some fine-sand-silt-clay stations that consistently showed signs of advanced succession stages up to 2013 did not show evidence of Stage III fauna (NF08, NF22, and NF24) while others did (NF12 and NF21; Figure 3-27).

When baseline conditions (1992 to 2000) are compared with post-diversion (2001 to 2017), SPI data exhibit no evidence of any outfall effect on benthic habitat quality (Table 3-6). The most likely change expected from outfall operation would have been an increase in sedimentary organic matter near the outfall, which would drive a shallowing of the aRPD layer and an increase in opportunistic Stage I fauna. There has not been any increase in organic matter or opportunistic species near the outfall or in the nearfield region (Section 3.1). The grand average apparent color redox-potential discontinuity layer depths (aRPD) for the last five years (2013 to 2017) have been the deepest measured since 1992, with 2013 the deepest and 2017 the fifth deepest (Figure 3-20).

From 1992 to 2017, changes and trends in SPI variables at nearfield stations appeared to be related to broader regional forcing factors. Similarly, trends in infaunal variables also appeared to be regional and unrelated to outfall operation with total abundance declining (Linear Regression, $df = 1$, $F = 12.6$, $p = 0.002$) and H' diversity increasing (Linear Regression, $df = 1$, $F = 7.7$, $p = 0.012$), through time (Nestler et al. 2017). Consistent with the decline in total infaunal abundance, the total number of biogenic structures observed in SPI also declined through time (Figure 3-31).

The dominance of hydrodynamic and physical factors related to storm events (high bottom stresses, currents, turbulence, and sediment transport) along with the high quality of the effluent discharged (Butman et al. 2008, Warner et al. 2008, Taylor 2010, Taylor et al. 2010), are the principal reasons that benthic habitat quality has remained high in the nearfield area. The high-energy environment in the region of the outfall disperses effluents quickly and prevents degradation of soft bottom benthic infaunal habitat. The lack of accumulation of organic matter in the sediments is the principle reason for lack of benthic impacts. In general, coastal ocean sewage outfalls with low or no detectable impacts in benthic infauna are associated with low accumulation rates for organic matter and dominance of high energy physical processes (Puente and Diaz 2015).

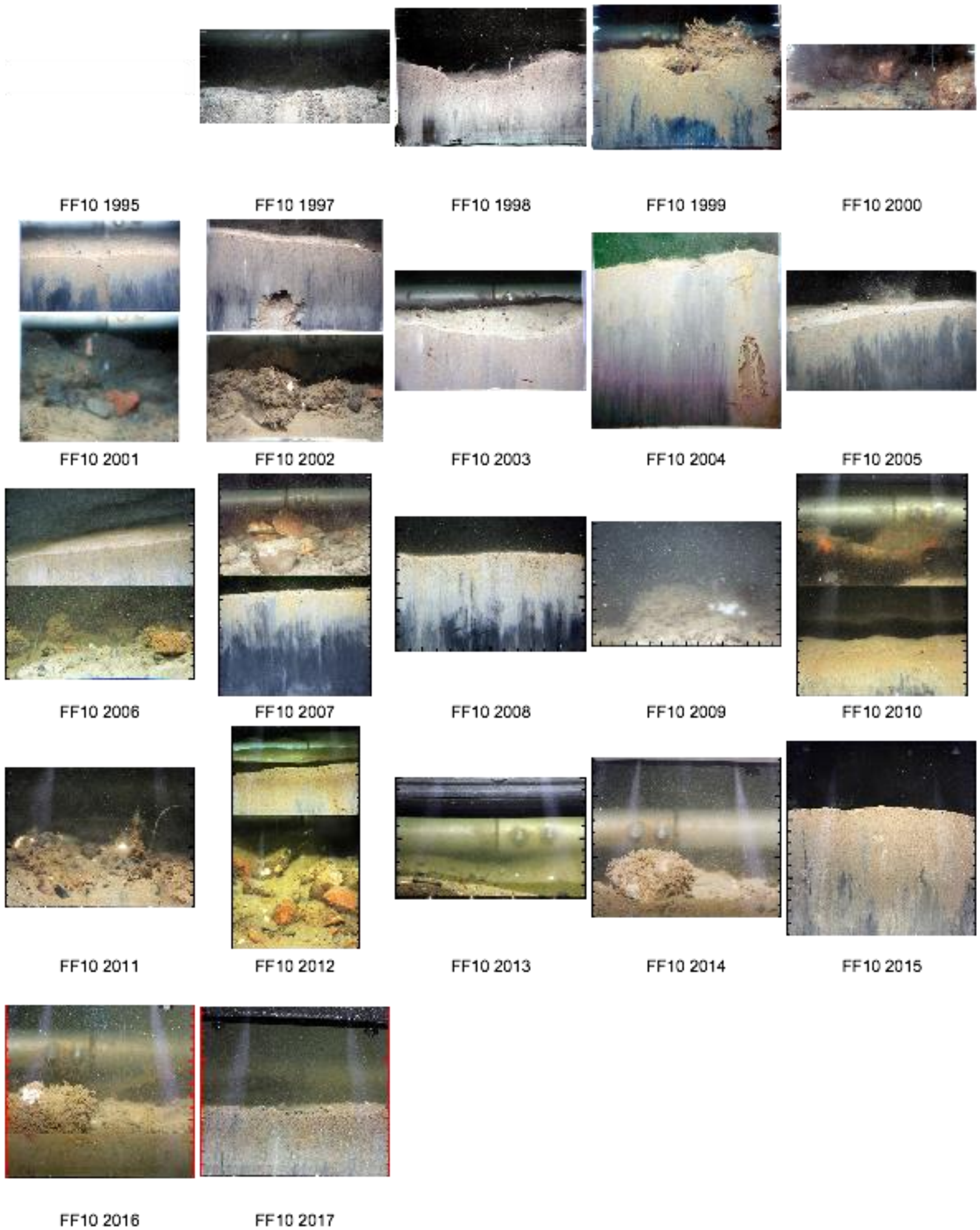


**Figure 3-29. Mosaic of SPI images for station FF10 that had a high degree of temporal variation in grain-size. Scale on side of images is in cm.**

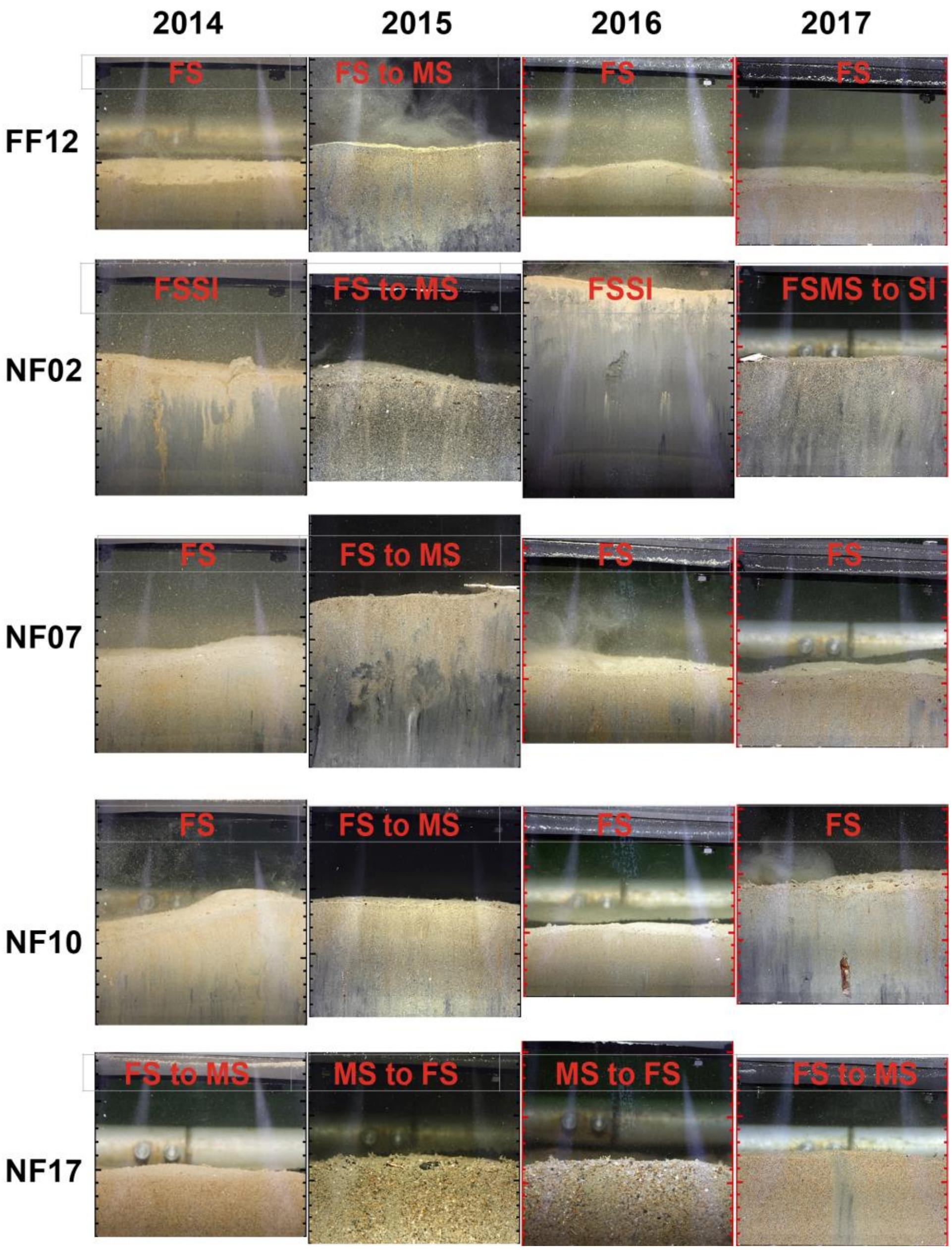


**Figure 3-30. Apparent change in modal sediment grain-size at nearfield stations between 2014 and 2017. FS = fine-sand, MS = medium-sand, SI = silt. Scale on side of images is in cm.**

**Table 3-7. Percent fines (silt+clay) at stations that appeared to change modal sediment grain-size between 2014 and 2017.**

| | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|
| FF12 | 22.7 | 18.3 | 28.4 | 25.0 |
| NF10 | 29.5 | 20.1 | 27.6 | 34.8 |
| NF17 | 1.2 | 2.2 | 1.4 | 5.5 |

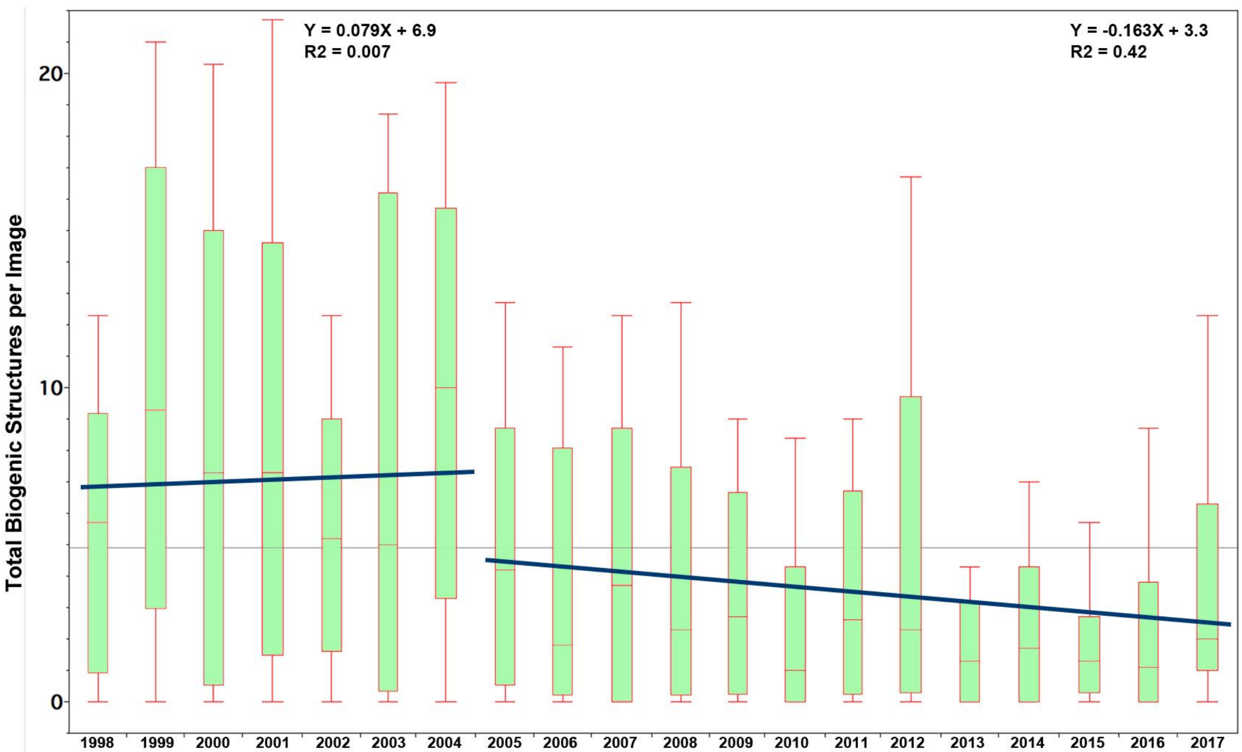


**Figure 3-31. Box-plot of annual total biogenic structures (sum of infauna, burrows, oxic and anaerobic voids) observed in SPI for all nearfield stations. Box is interquartile range (IR = center 50% of observations), line in box is median, tails are 1.5xIR. Horizontal gray line is grand median for all years. Breakpoint regression lines are based on medians.**

## 3.4 Hard-bottom Benthic Habitats and Fauna

### 3.4.1 2017 Results

Photographic coverage of the hard bottom habitat in the vicinity of the outfall in 2017 ranged from 16 to 24 minutes of video footage at each waypoint and a total of 480 minutes of video was viewed and analyzed. The video footage taken this year was collected in the same manner as was utilized in 2014. The vehicle used to survey the stations was a *Benthos Mini-Rover* equipped with an analog video camera. The *Benthos Mini-Rover* is less powerful than the *Outland 1000* ROV used during some of the earlier surveys and is also acoustically noisier. This aspect of the ROV may scare some mobile fauna away from the path of the survey. A *GoPro Hero 4* camera attached to the *Mini-Rover* was used to simultaneously collect HD video and still images along the dive track for future use if deemed necessary. A summary of the analysis of the 2017 analog video is included in Appendix B.

Data collected from the video taken during the 2017 survey was generally similar to data obtained from previous post-diversion surveys. The seafloor on the tops of drumlins consisted of a moderate to moderately high relief mix of glacial erratics in the boulder and cobble size categories, while the seafloor on the flanks of drumlins frequently consisted of a low to moderately low relief seafloor characterized by cobbles with occasional boulders. Sediment drape generally ranged from moderately light to moderate on the tops of drumlins and moderate to moderately heavy on the flanks of drumlins. As has been observed in previous years, habitat relief and sediment drape were quite variable within many of the sites surveyed. The seafloor in the vicinity of both diffuser heads consisted of angular rocks in the small boulder size category. This resulted in a high relief island (the diffuser head) surrounded by a moderate relief field of small boulders. Drape at the diffuser sites was moderately heavy.

The species seen during the 2017 survey are shown in Appendix C. A total of fifty-five taxa, 4 algal species, 37 invertebrate species, 8 fish species, and 6 general catagories were seen during the 2017 video analyses. The species and the number of species have remained relatively constant over the course of this study. The distribution of the species has also remained relatively constant during the last several years. Coralline algae continued to be the most common and widespread component of the benthic communities, being found at 20 of the 23 waypoints. Another algal species, *Palmaria palmata* (dulse) was also seen in numbers similar to those observed in previous years. This red alga was found at 16 of the stations and was commonly seen at eight of them. In contrast, two other algal species were seen in lower abundances than previously. *Ptilota serrata*, a filamentous red alga was seen at only 5 stations and was present in sizable numbers at only two of the sites. Very few of the fourth algal species *Agarum cribrosum* (shotgun kelp) were seen, with only a few fronds observed at two locations. This is similar to what was observed in 2014.

Common invertebrates seen in 2017 included: the horse mussel *Modiolus*, juvenile and adult northern sea stars *Asterias vulgaris,* the blood star *Henricia sanguinolenta,* white and cream encrusting tunicates (*Aplidium*/*Didemnum* spp.), the encrusting yellow sponge *Polymastia* sp. A, the sea peach tunicate *Halocynthia pyriformis,* and the brachiopod *Terebratulina septentrionalis*. Their abundances and distributions were also similar to those observed in previous years. The similarity to previous years also extended to the fish taxa, with the cunner *Tautogolabrus adspersus* being by far the most abundant and widely distributed fish encountered within the study area.

The taxa inhabiting the diffuser heads of the outfall continued to remain stable over time and did not change when the outfall went online. The inactive diffuser head (Diffuser #44) continued to support sparse populations of the frilled anemone *Metridium senile* and the sea peach tunicate *Halocynthia pyriformis*, while the riprap at the base mainly supported dense stands of hydroids (Figure 3-32 a & b). Dead barnacles were also observed on top of the diffuser head. In contrast, the active diffuser head (Diffuser #2 at T2-5) supported a very dense population of *M. senile*, with anemones covering much of the available surfaces of the diffuser head (Figure 3-32 c & d). Surfaces on top of the diffuser head that were not covered by anemones were colonized by a very dense stand of barnacles *Balanus* sp. most of which were dying off. Additionally, numerous *M. senile* and dense stands of the hydroid *Tubularia* sp. have colonized the riprap around the base of the diffuser.

Several other observations were made during the 2017 survey. Massive settlements of barnacles *Balanus* sp., many of which were in the process of dying-off, were found at many of the stations. At 16 of the stations, numerous boulders were totally covered with the base plates and/or valves of dead barnacles and at another 3 stations abundances were lower but the surfaces of some of the boulders were similarly covered. The exception to this was that few barnacles, dead or alive, were observed at the three near-field southern reference sites (T8-1, T8-2 and T12-1). In areas of massive settlements of barnacles adult northern sea stars *Asterias vulgaris* were frequently seen preying on the barnacles. A similar pattern of massive settlements of *Balanus* sp. was also observed in 2014.

Anomalies were also noted in the numbers and distribution of two commonly seen sponge species. During the 2017 survey, the fig sponge *Suberites* spp. was observed at only 1 station, the southernmost reference station T11-1 off Scituate, MA. In contrast, during prior years its distribution was much more widespread, being observed at 9 to 15 stations during the pre-diversion period and 12 to 17 stations during the post-diversion period. This species was traditionally most abundant on the drumlins located immediately north and south of the outfall (T1, T2, T4 and T6). The other sponge, an unidentified white sponge that usually encrusted the valves of brachiopods *Terebratulina septentrionalis*, was also found at only 1 station (T2-2) in 2017. Historically this sponge was observed at 2 to 15 stations, usually at all stations that supported brachiopods. In 2017, even though brachiopods were observed at 10 stations the sponge was found at only one. Additionally in previous years most brachiopods seen were encrusted by the sponge, which was certainly not the case in 2017.

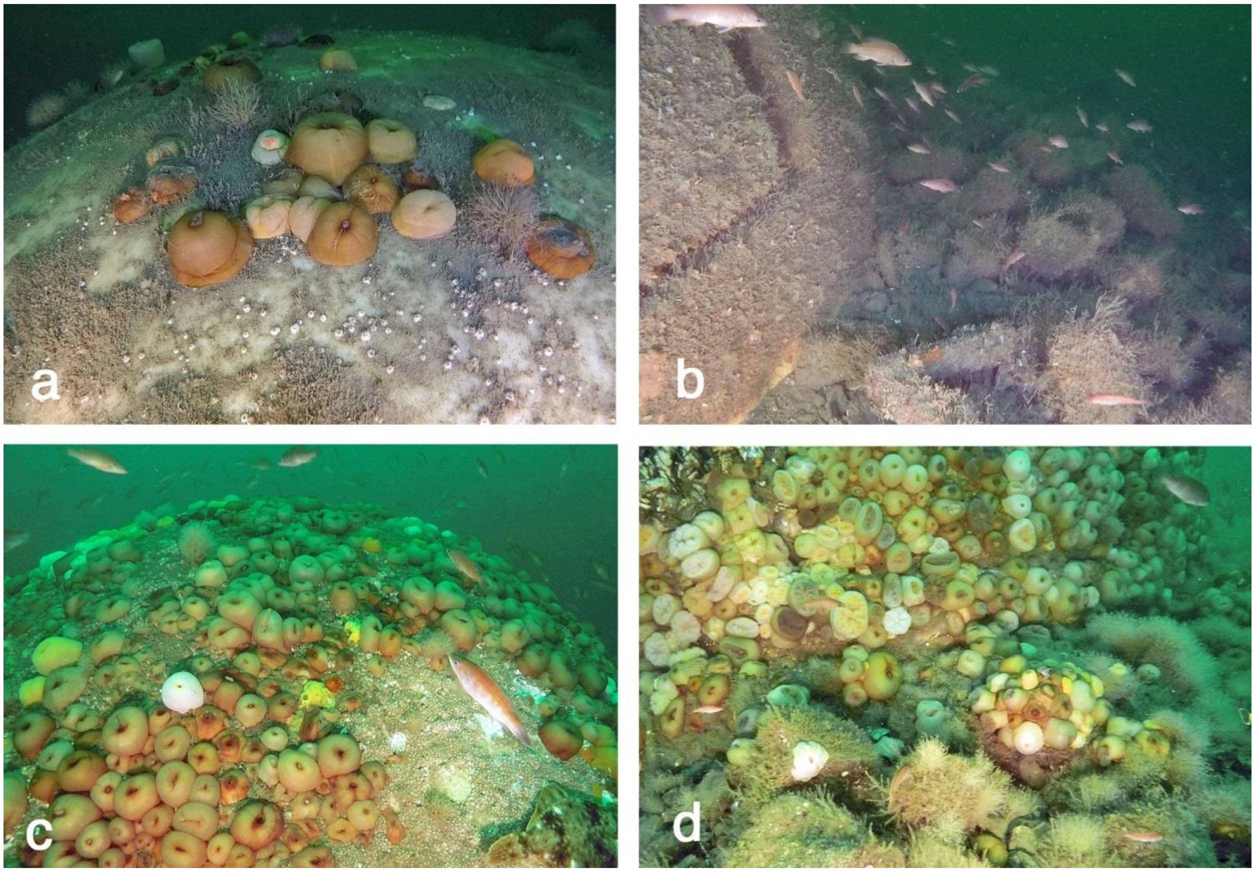


**Figure 3-32. Still images taken at inactive diffuser head #44 (a & b) and active diffuser head #2 (c & d) during the 2017 hard-bottom survey. (a) A sparse population of frilled anemones *Metridium senile* colonizing the top of diffuser head #44, with a colony of the hydroid *Tubularia* sp., a green urchin *Strongylocentrotus droebachiensis* visible at the upper left and numerous small barnacles. (b) The base of diffuser head #44 showing the heavy drape, hydroids and numerous cunner *Tautogolabrus adspersus* responding to the structural heterogeneity of the head. (c) Numerous frilled anemones *Metridium senile* colonizing the top of active diffuser head #2. A heavy settlement of barnacles occupies all surfaces that are not covered by anemones and dying off barnacles are seen as patches of white in the lower right quadrant. Cunner are seen hovering over the top of the head, while several colonies of *Tubularia* sp. and part of a winter flounder (lower right corner) are also visible. (d) Numerous *M. senile* colonizing the base of diffuser head #2 and spilling out onto the surrounding riprap. Blue mussels *Mytilus edulis* growing in an active port are seen at the top left, while the hydroid *Tubularia* sp. is seen on the riprap at the base.**

### 3.4.2 Comparison of 2017 Data with Pre- and Post-Diversion Results

Previously described general trends of decreased percent cover of coralline algae and declines in the number of upright algae in post-discharge years continued into 2017. Encrusting coralline algae has historically been the most abundant and widely distributed taxon encountered during the hard-bottom surveys. Table 3-8 presents the relative cover of coralline algae observed in video footage taken during the 1996 through 2017 surveys. Coralline algae were generally most abundant on the tops of drumlins on either side of the outfall (T1-2, T1-3, T1-4, and T4/6-1) and two southern reference sites (T8-1 and T8-2), and least abundant on the flanks of the drumlins (T2-2, T2-4, T4-2, and T6-1). The percent cover of coralline algae was quite stable during the baseline period and remained stable at most of the stations during the first four years of the post-diversion period. A decrease in coralline algae cover started at the northern reference sites in 2002 and has persisted; a similar reduction has been evident at three drumlin top sites north of the diffuser (T1-2, T1-3, and T1-4) since 2004. Less pronounced decreases in cover of coralline algae are seen at several other sites since 2006. This pattern differs slightly from that observed in the analysis of the still images, where waypoints T1-2, T1-3, T1-4, T7-1, and T7-2, consistently have had less percent cover of coralline algae since 2001. The subsequent decrease in cover of coralline algae in 2005 and the spread of this decrease to the southern areas was observed in both the video and still images, although less pronounced in the data collected from video images.

The relative abundances of upright algae generally varied widely during both the pre- and post-diversion periods. Additionally, at many sites the upright algae have shown a general decrease over time. The observed variability appears to reflect both patchiness in the spatial distributions of the upright algae and natural cycles in the composition of algal communities. Table 3-9 shows the relative abundance of *Palmaria palmata* over the 1996 to 2017 time period. Dulse was consistently most abundant at the northern reference sites and common at two waypoints north of the outfall, during the pre-diversion period. The relative abundance of *P. palmata* has decreased at these five sites during most of the post-diversion years, and additionally it dropped to an area-wide low in 2003 and 2004. In contrast, since 2005 dulse has been seen in modest abundances at stations where it had historically been largely absent, such as on the drumlin immediately north of the outfall, and at two of the southern reference sites following a pattern observed in still images collected between 1996 and 2008.

Table 3-10 shows the relative abundance of *Ptilota serrata* over the 1996 to 2017 time period. Historically, this filamentous red alga was consistently most abundant at the northern reference sites, and only occasionally common to abundant at sites on drumlins on either side of the outfall. The relative abundance of *P. serrata* has decreased at the northern reference sites over time, and has virtually disappeared at many of the other sites during most of the post-diversion years. Abundances of *P. serrata* reached an all-time low at all stations during 2007, when it was observed in very modest abundances at only three of the sites. This alga does appear to rebound occasionally at the northern reference sites. It is also appearing in sizable abundances at several drumlin top sites north of the outfall, and at one of the southern reference sites. Similar patterns were also observed in the data collected from still images between 1996 and 2008. These patterns may reflect different stages in a successional sequence of algal communities.

**Table 3-8. Relative cover of coralline algae observed in video footage taken during the 1996 to 2017 hard-bottom surveys. An asterisk (*) denotes a very patchy distribution.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2014 | 2017 |
| Northern reference | T7-1 | c-a | a | c-a | c | c-a | c-a | f-c | c | c | f-c | f-c | f-c | f-a | f-c | f-c | f-c | f | c |
| | T7-2 | c-a | c-va | c-a | c | c-a | f-c | c | f-c | c | f-c | f-c | c | c-a | f-c | f-c | c | c | c |
| | T9-1 | | c-a | c-a | c | c | c-a | c | f-c | c | f-c | c | c | c | f-c | f-c | c | f-c | f-c |
| Northern transect | T1-1 | va | c | c-a | c | c | f-c | f-c | f-c | c | f-c | f-c | f-c | f-c | f-c | f | f | f | f |
| | T1-2 | a | va | a | c* | a | c-a | c | a | f-c | c-a | c | c-a | c-a | c-a | c | f-c | c-a | r |
| | T1-3 | a | va | a | va | a | va | a | a | a | a | c | c-a | c | c-a | c-a | c | c-a | c |
| | T1-4 | va | va | a | a | a | a | a | a | c-a | c-a | c-a | c-a | c-a | c-a | c-a | c | c | c-a |
| | T1-5 | a* | c | c | c | c-a | f-c | f-c | c | c | f | r-f | f | r-f | f | f | f | r-f | c |
| | T2-1 | f-a | f-c | r-f* | c | c | f-c | c | c-a | c | f | c | f-a | f-c | f | c | f-c | f-c | f |
| | T2-2 | r | f | f-c* | r-c | c | f-c | r-f | f | f | f | r | r-f | f | f | f | f | r | f |
| | T2-3 | c | r | c | c | f* | f-c | f-c | f-c | f | f | f-c | r-f | f-c | f | f | f | r | f-c |
| | T2-4 | f | r | f | f | - | r | f | r-f | r | r | r | f | r-f | f | r | r | - | r |
| Southern transect | T4/6-1 | va | c-a | a | a | a | va | a | a | a | a | a | c-a | c-a | a | a | a | a | c |
| | T4-1 | r | f | r | - | f-c | - | r | | | | | | | | | | | - |
| | T4-2 | c | c-a | r-f* | f* | c | c | f-c | f | f-c | f-c | f-c | r | f | f | r-f | r-f | r | f |
| | T4-3 | f | f | c | f-c | c | f-c | c | | | | | | | | | | | - |
| | T6-1 | r | r | r | r | r | r | - | r | - | - | - | - | - | r | r | - | - | r |
| | T6-2 | c-a* | c | c-a | c | c | c | c | f-c | f-c | f-c | f | f | f-c | c | c-a | f | c | r-f |
| Southern reference | T10-1 | | r-f | - | r | r | - | r | - | r-c | r | - | - | - | - | r-f | r | - | - |
| | T8-1 | a | c-a | a | c-a | c | a | c-a | c-a | c-a | a | c | c-a | f-c | c | c-a | c-a | f-c | f-c |
| | T8-2 | a | a-va | a | c | a | c-a | c | a | a | a | c-a | c-a | c-a | c-a | c-a | c-a | f-c | c-a |
| | T12-1 | | | | | | | | c-a | c-a | c | c-a | | c | c-a | c | c | c | c-a |
| | T11-1 | | | | | | | | - | f | f | f | r-f | | f | r-f | f | f | f |
| Diffusers | T2-5 | - | - | | | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | RR | - | r | r | | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | D#44 | | | - | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | RR | | | - | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

| a | c-a | c | f-c | f | r-f | r | - |
|---|---|---|---|---|---|---|---|
| abundant | | common | | few | | rare | none |

**Table 3-9. Relative abundance of *Palmaria palmata* (dulse) observed in video footage taken during the 1996 to 2017 hard-bottom surveys. An asterisk (*) denotes a very patchy distribution.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2014 | 2017 |
| Northern reference | T7-1 | c | c-a | f | c | c-a | c-a | c-a | c | f-c | c-a | c-a | f-c | c-a | f-a | f-c | f-a | f-c | f-c |
| | T7-2 | c | c | c-a | c-a | c | a | c-a | c-a | a | c | f-c | f-c | f | r-c | f-a | f-c | c | c-a |
| | T9-1 | | a-va | c | a | a | c-a | c | r-f | f | r-c | f | f | f | f-c | f-c | f | f-c | r-f |
| Northern transect | T1-1 | a | a | c | c | f-c | f-c | c | f | f | c | f | r-f | f-c | c | f-c | f-c | f-c | r-f |
| | T1-2 | f | - | r | f | - | r-f | - | r | r | r | f-c | f | f-c | f | c-a | c | f | c |
| | T1-3 | - | - | r | - | r | f | f | f | r | f-c | f-c | f-c | c-a | f-a | c-a | c-a | c | c-a |
| | T1-4 | - | - | - | - | - | r | - | f | r | f | f | f | f-c | f-c | f-a | f-c | c | r-f |
| | T1-5 | r* | - | - | - | - | - | - | r | - | - | - | r | r | r | r | r | r | - |
| | T2-1 | - | c | - | f | r | f | r | r | - | - | r | - | r-f | r-f | r | f | r | r-f |
| | T2-2 | - | va | c | c | - | - | c | - | - | r-f | - | - | r | - | - | - | - | r |
| | T2-3 | c | c | c | c | c | f-c | c | - | f | f | f-c | f | f | f-c | f-c | f | r-f | f-c |
| | T2-4 | c | c | f-c | r | - | r-f | - | - | - | - | - | - | r | - | - | - | - | r |
| Southern transect | T4/6-1 | f | c* | - | r | r | r | - | r | - | - | r | r | r | r-f | r-f | f | f | f |
| | T4-1 | - | - | - | - | - | - | - | | | | | | | | | | | |
| | T4-2 | - | - | - | - | - | - | - | - | - | - | f | r | - | - | - | r-f | - | - |
| | T4-3 | - | - | - | - | - | - | - | | | | | | | | | | | |
| | T6-1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T6-2 | c* | - | r | - | - | - | - | - | - | - | - | - | - | r-f | r-f | - | r | - |
| Southern reference | T10-1 | | c-a | r | c | c | r | f-c | r | f-c | f | f | r | - | f | f-c | f-c | - | f |
| | T8-1 | - | - | - | - | - | - | - | - | r | f | r-c | f | f-c | r-f | f-c | f-c | r-f | f-c |
| | T8-2 | - | - | - | - | - | - | - | - | - | r | f | r | r | r-f | r | f | r | f-c |
| | T12-1 | | | | | | | | f | f | f | f-c | | f-a | f-c | f-c | c | c | f-c |
| | T11-1 | | | | | | | | - | - | - | - | - | | r-f | r | r | - | - |
| Diffusers | T2-5 | - | - | | | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | RR | - | - | - | | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | D#44 | | | - | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | RR | | | - | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

| a | c-a | c | f-c | f | r-f | r | - |
|---|---|---|---|---|---|---|---|
| abundant | | common | | few | | rare | none |

**Table 3-10. Relative abundance of *Ptilota serrata* (filamentous red alga) observed in video footage taken during the 1996 to 2017 hard-bottom surveys. An asterisk (*) denotes a very patchy distribution.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2014 | 2017 |
| Northern reference | T7-1 | va | c-a | a | a | c | c-a | c-a | c-a | f-a | c-a | c-a | f-c | c-a | f-a | f-c | f-c | f | f |
| | T7-2 | va | c-a | a | a | c-a | a | c | c-a | a | a | f-a | f-c | f-c | r-c | f-a | f-c | f-c | f |
| | T9-1 | | a-va | c-a | a | c-a | c | f-c | r | f | r-c | - | - | - | f-c | f-c | f | - | - |
| Northern transect | T1-1 | a | - | c-a | - | - | - | f | - | - | - | - | - | - | f | - | - | - | - |
| | T1-2 | a | - | f | - | - | - | - | - | - | - | - | - | - | f-c | f-c | c | - | - |
| | T1-3 | f | - | f | - | - | f | - | r | c-a | r | r-c | f-c | c-a | c-a | c-a | a | c | c |
| | T1-4 | r-f | - | - | - | - | - | - | - | r-f | - | f | - | f-c | c-a | f-a | f-c | c-a | - |
| | T1-5 | f-c* | - | - | - | - | - | - | - | - | - | r-f | - | - | r-f | - | - | - | - |
| | T2-1 | f | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T2-2 | f | c | a* | c | - | - | - | - | - | - | - | - | - | - | - | - | - | r |
| | T2-3 | a | - | c-a | f-c | f-c | - | r-f | - | - | - | r | - | - | - | - | - | - | - |
| | T2-4 | a | r | c | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Southern transect | T4/6-1 | c-va | c-a | f | f | - | - | - | - | - | - | - | - | r | r-f | r-f | f-c | f-c | - |
| | T4-1 | - | - | - | - | - | - | - | | | | | | | | | | | |
| | T4-2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T4-3 | - | - | - | - | - | - | - | | | | | | | | | | | |
| | T6-1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T6-2 | c-va* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Southern reference | T10-1 | | c-a | f-c | f | - | - | - | - | - | - | - | - | - | r | r | - | - | - |
| | T8-1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | r | - | - |
| | T8-2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T12-1 | | | | | | | | f-c | f-c | - | f | | f-a | f-c | c-a | c-a | a | f-a* |
| | T11-1 | | | | | | | | - | - | - | - | - | | - | - | - | - | - |
| Diffusers | T2-5 | - | - | | | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | RR | - | - | - | | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | D#44 | | | - | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | RR | | | - | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

| a | c-a | c | f-c | f | r-f | r | - |
|---|---|---|---|---|---|---|---|
| abundant | | common | | few | | rare | none |

Another upright alga, the shotgun kelp *Agarum cribrosum*, has historically been consistently abundant only at the northern reference sites. This species was frequently quite patchy even within waypoints, with many *A. cribrosum* fronds observed in some areas while none were observed in adjacent areas. There has been a general decrease in shotgun kelp at all of the northern reference sites. This species was occasionally encountered at a few of the other waypoints during the pre-diversion period, but has rarely been encountered elsewhere in the post diversion period. Data collected from the slide images showed a dramatic decline in *A. cribrosum* at T7-1 from a high in 2000, when it was heavily overgrown by the invasive bryozoan *Membranipora membranipora*. This decline was much less evident in the data collected from video images. In 2010 and 2011 this algae was also seen at one site north of the outfall. In 2014, the number of *A. cribrosum* was at an all-time low, with only a few fronds being observed at one of the northern reference sites. Specifics of the abundance and distribution of shotgun kelp over the time course of this study can be seen in Appendix A3.

Part of the decline in both coralline and upright algae at the northern reference sites during the post diversion period may reflect post 9/11 increases in anchoring activity of tankers at these sites. Disturbed areas of the seafloor have been observed at all three northern reference sites during multiple years since outfall start-up. This may result in a seafloor that is a mosaic of areas in differing stages of recovery from physical disturbance.

Table 3-11 shows long-term trends that have been noted in the abundances of some of the larger mobile taxa over time. These trends appear to reflect widespread temporal changes in abundances rather than changes related to the outfall, since they were evident at both outfall and reference sites. The numbers of *Cancer* crabs, Atlantic cod (*Gadus morhua*), American lobster (*Homarus americanus*), and winter flounder (*Pseudopleuronectes americanus*) observed during the surveys have generally increased over time. The number of *Cancer* crabs seen annually ranged from 0.6 to 3.6 individuals per 100 minutes of video between 1996 and 1999, to 6.4 to 39.1 individuals per 100 minutes of video between 2001 and 2017. The abundance of crabs varies widely and appears to undergo several-year cycles of abundances, but the general trend has been towards more crabs over time. The number of lobsters seen during the surveys has also increased over time, ranging from 0.5 to 4.1 individuals per 100 minutes of video per year in the pre-diversion period to 2.3 to 18 individuals per 100 minutes of video per year in the post diversion period. Cod have shown a similar pattern with zero to 5.2 individuals per 100 minutes of video annually during the pre-diversion years and 7.2 to 20.3 individuals per 100 minutes of video annually during all but three of the post diversion years. The low number of cod seen during the 2014 and 2017 surveys may in part reflect cod shying away from the acoustically noisier *Benthos Mini-Rover* and high levels of suspended matter reducing visibility. Winter flounder appear to have increased in abundance only since 2008, ranging from 2.5 to 8.1 individuals per 100 minutes of video seen during the pre-diversion period, 1.9 to 5.3 individuals per 100 minutes video seen in the earlier part of the post-diversion period, and 8.7 to 17.1 individuals per 100 minutes of video seen in the later post-diversion period. Flounder are usually less skittish than cod, frequently allowing the ROV to closely approach them. Hence, their observed abundances might not be as easily influenced by the acoustic characteristics of the ROV.

**Table 3-11. Number of several large mobile commercially important species observed in video footage taken during the 1996 to 2017 hard-bottom surveys (standardized to number seen per 100 minutes of video).**

| | Pre-discharge | | | | | Post-discharge | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2014 | 2017 |
| ***Gadus morhua* (cod)** | - | 1.4 | 2.7 | 5.2 | 2.5 | 9.2 | 10.7 | 2.1 | 11.5 | 13.7 | 14.1 | 9.1 | 14.4 | 20.3 | 7.2 | 6.7 | 2.0 | 2.3 |
| ***Pseudopleuronectes americanus* (winter flounder)** | 4.6 | 2.9 | 6.8 | 8.1 | 2.5 | 4.0 | 3.8 | 1.9 | 5.3 | 3.6 | 2.6 | 3.6 | 10.6 | 8.9 | 17.1 | 12.9 | 9.4 | 8.7 |
| ***Cancer* spp. (rock crab)** | 1.4 | 0.6 | 0.9 | 3.6 | 20.9 | 27.5 | 33.9 | 30.7 | 25.3 | 14.4 | 19.3 | 24.5 | 6.3 | 19.0 | 6.4 | 7.1 | 39.1 | 10.7 |
| ***Homarus americanus* (lobster)** | 1.4 | 0.5 | 2.5 | 0.9 | 4.1 | 4.8 | 7.1 | 7.5 | 2.7 | 2.3 | 8.0 | 8.2 | 2.7 | 18.0 | 8.0 | 9.4 | 9.1 | 9.6 |

One noticeable difference seen during both the 2014 and 2017 surveys was the widespread presence of dead or dying barnacle sets at many of the stations. Large areas of rock surfaces covered by dead or dying barnacles were observed at 15 stations in 2014 and 16 stations in 2017. These stations were spread throughout the study area with the exception of the southern reference sites in 2017. Additionally, live barnacles were only observed in high numbers at one site (T4/6-1) in 2014, whereas in 2017 they were observed in high numbers at 12 sites. Similar instances of large areas of dead barnacle sets have been noted several times in previous years, but never as dominantly or as widely spread as those observed in 2014 and 2017. The heavy settlement in 2017 does coincide with higher numbers of barnacle nauplii available in the water column during spring of 2016 (Libby et. al. 2017).

The pronounced decrease in two of the sponge taxa, the fig sponge *Suberites* spp. and the white sponge encrusting brachiopod valves, is a bit perplexing. The fig sponge typically attaches onto larger boulders and may well have been outcompeted by the massive barnacle sets occupying available settlement space. Although, if this were the only reason for the decline in *Suberites* spp. then we would have also expected a similar decline in 2014, which did not happen (Table 3-12). The explanation for the decrease in the sponge encrusting brachiopods is a bit more problematic. The brachiopods were there but most of them did not have sponge covering. Whether the brachiopods were newly attached and had not yet acquired a sponge covering is presently not known. It is interesting to note that the sponges are filter feeders and might be expected to be more sensitive to changes in their environment than other taxa. Conversely the observed changes may simply be related to competition for available settlement space with the heavy influx of barnacle sets.

The data obtained from an analysis of the video images showed similar patterns to that observed in data obtained from analysis of the slides. The data from the video analysis was not quite as sensitive as that obtained from the slides, and also showed a slight time lag in discerning changes. This is not surprising since the data from the video is frequently a range of relative abundances encountered at a waypoint rather than a discrete number that represents an average of 25 to 30 slides. Ranges would be much less sensitive to subtle changes in the relative abundances of the biota. However, both techniques showed similar patterns, so the video analysis appears to be sensitive enough to discern more dramatic changes. Examples of the visual changes observed over time at a few representative sites can be seen in the plates in Appendix D.

**Table 3-12. Relative abundance of the fig sponge *Suberites spp.* observed in video footage taken during the 1996 to 2017 hard-bottom surveys.**

| | | Pre-diversion | | | | | Post diversion | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2014 | 2017 |
| Northern reference | T7-1 | - | - | - | - | - | - | f | - | r | - | - | - | - | - | r | - | - | - |
| | T7-2 | r | r | - | - | - | - | f | r | r | - | - | - | r | - | r | - | - | - |
| | T9-1 | - | f | f | - | f | r | f | - | - | r | - | c | r-f | - | f | - | f | - |
| Northern transect | T1-1 | r | - | f | c | f | c | f | c | c | f | f | f | f-c | f | f-c | f-c | f | - |
| | T1-2 | - | - | - | c | f | - | - | - | f | - | - | - | - | - | - | r | - | - |
| | T1-3 | - | - | - | f | - | r | - | - | - | - | - | - | - | - | - | - | r | - |
| | T1-4 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | T1-5 | - | r | f | c | f | f | f | c | f | f | f-c | c | f-c | c | c | f-c | f | - |
| | T2-1 | r | f | f-c | c | f | c | c | f | f-c | f | c | f-c | f-c | f | c | f | f | - |
| | T2-2 | a | c | - | c | c | c | f | c | f-c | f | c | c | c | c | c | c | f | - |
| | T2-3 | c | r | c | c | f | c | c | c | f | f | f | f-c | c | f-c | c | f-c | r | - |
| | T2-4 | a | f | c | c | c | c | c | f-c | f-c | f | f | f-c | f | f | f-c | f-c | c | - |
| Southern transect | T4/6-1 | - | r | - | - | - | - | - | - | - | - | - | r | - | - | - | - | - | - |
| | T4-1 | - | - | - | r | r-c | - | r | - | - | - | - | - | - | - | - | - | - | - |
| | T4-2 | c | r | f | c | c-a | f-c | r | c | f | f-c | f | f | f | r-f | r | c | f | - |
| | T4-3 | f | c | f | f | c | c | c | - | - | - | - | - | - | - | - | - | - | - |
| | T6-1 | - | r | f | f-c | f-c | r | f | f | f | f | - | - | - | r | r | - | - | - |
| | T6-2 | - | r | f-c | c | c | c | f-c | c | f | f | c | f-c | f-c | f | r | c | r | - |
| Southern reference | T10-1 | - | - | - | - | - | - | - | r | - | f | f | c | c | f | f | c | f-c | - |
| | T8-1 | - | - | - | r | - | - | - | - | - | - | - | - | f | - | - | r | r | - |
| | T8-2 | r | - | f | r | - | - | r | - | - | - | f | r | r | r | r | - | f | - |
| | T12-1 | - | - | - | - | - | - | - | - | r | - | r | - | r | - | - | r | - | - |
| | T11-1 | - | - | - | - | - | - | - | c | c | c | f-c | f-c | - | f | c | c | c | c |
| Diffusers | T2-5 | - | - | | - | - | - | - | - | - | - | r | - | - | r | f | f | - | - |
| | RR | - | - | c | - | - | - | - | - | - | - | r | - | - | r | f | r | - | |
| | D#44 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | r | - | - |
| | RR | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | r | - | |

| a | c-a | c | f-c | f | r-f | r | - |
|---|---|---|---|---|---|---|---|
| abundant | | common | | few | | rare | none |

*Has the hard-bottom community changed?*

The hard-bottom benthic communities near the outfall remained relatively stable over the 1996–2000 baseline time period, and have not changed substantially with activation of the outfall in September 2000. Major departures from baseline conditions have not occurred during the post-diversion years; however, some modest changes have been observed. Increases in sediment drape, and concurrent decreases in cover of coralline algae, were observed at several drumlin-top sites north of the outfall and at the two northernmost reference sites during all of the post-diversion years. The decrease in coralline algae became more pronounced in 2005 and spread to a number of additional sites south of the outfall. Decreased cover of coralline algae at the stations close to the outfall may be related to the diversion, or may just reflect long-term changes in sedimentation, and hence coralline algae, patterns. Additionally, a decrease in the number of upright algae was observed at many of the stations. However, it is unlikely that this decrease was attributable to diversion of the outfall, since the general decline had started in the late 1990s and the number of upright algae appears to be increasing again at a number of stations. The decline has been quite pronounced at the northern reference stations and may reflect physical disturbance of the seafloor, possibly due to anchoring of tankers at these locations following September 11, 2001. Disturbance of the seafloor in the form of overturned boulders and areas of shell lag has been noticed at the northern reference sites. In recent years we have been noticing several other changes. Lush epifaunal growth continues to thrive on the diffuser heads surveyed for this study and throughout many of the other stations visited. The noticeable changes observed recently may reflect natural variability in the benthic communities or may represent other shifts in the environment. The massive and widespread barnacle settlement events observed in 2014 and 2017 may reflect natural cycles in the population. In contrast, the observed decrease in abundance and distribution of two of the sponge taxa may reflect competition among sessile fauna for settlement space or may be the result of cumulative, modest outfall impact. So while outfall impacts have appeared to be minimal over time, changes in the hard-bottom communities could be chronic and/or cumulative, and may take longer to manifest themselves.

# 4. SUMMARY OF RELEVANCE TO MONITORING OBJECTIVES

Benthic monitoring for MWRA's offshore ocean outfall is focused on addressing three primary concerns regarding potential impacts to the benthos from the wastewater discharge: (1) eutrophication and related low levels of dissolved oxygen; (2) accumulation of toxic contaminants in depositional areas; and (3) smothering of animals by particulate matter.

Results of the SPI survey provide important insight into the question of eutrophication and dissolved oxygen. As has been noted throughout the post-diversion period, the 2017 SPI survey continued to find no indication that the wastewater discharge has resulted in low levels of dissolved oxygen in nearfield sediments. The average thickness of the sediment oxic layer in 2017 was greater than reported during the baseline period. The SPI results continued to suggest a trend towards a predominance of a pioneering stage benthic community, a result indicative of an increase in stress on the community. There is no evidence that this stress is caused by organic pollution; for example the infaunal study found that the numbers of opportunistic species remained negligible in 2017. The trend seen in the SPI survey was likely an artifact of the coarsening of sediment grain-size caused by sediment mixing and transport associated with storms that resulted in the decline in visible biogenic structures in the images. These results support previous findings that eutrophication and the associated decrease in oxygen levels have not been a problem at the nearfield benthic monitoring stations (Nestler et al. 2017, Maciolek et al. 2008). The outfall is located in an area dominated by hydrodynamic and physical factors, including tidal and storm currents, turbulence, and sediment transport (Butman et al. 2008). These physical factors, along with the high quality of the effluent discharged into the Bay (Taylor 2010), are the principal reasons that benthic habitat quality has remained high in the nearfield area.

Sediment contaminant loads measured in 2017 showed no indication that toxic contaminants from the wastewater discharge are accumulating in depositional areas surrounding the outfall, the same result observed when contaminants were last measured (Nestler et al. 2015). No Contingency Plan threshold exceedances for sediment contaminants have occurred to date, including in 2017. As seen in previous years, patterns in the spatial distribution of higher contaminant concentrations primarily reflect both the percentage of fine particles in the sediment, and the proximity to historic sources of contaminants in Boston Harbor (Nestler et al. 2015).

Surveys of soft-bottom benthic communities continue to suggest that animals near the outfall have not been smothered by particulate matter from the wastewater discharge. The percentage of fine grain sediments has not increased in the nearfield stations since the diversion indicating no pattern of settlement of particulate matter from the discharge. There were no Contingency Plan threshold exceedances for any infaunal diversity measures in 2017. Although upper limit exceedances had been reported for Shannon-Wiener Diversity (H’) and Pielou’s Evenness (J’) each year from 2010 to 2014, these occurred region-wide and were largely driven by relatively lower abundances in a small number of dominant species. As such, these exceedances were not related to the discharge and U.S. EPA has removed the upper level diversity thresholds from the Contingency Plan.

Hard-bottom benthic community monitoring in 2017 also found no evidence that particulate matter from the wastewater discharge has smothered benthic organisms. Although some modest changes in this community (e.g., coralline algae and upright algae cover) have been observed, comparisons between the post-diversion and baseline periods indicate that these changes are not substantial. Factors driving changes in the algal cover are unclear, but, since declines in upright algae started in the late 1990s (prior to wastewater diversion to the outfall), it is unlikely that the decrease was attributable to diversion of the outfall.

Benthic monitoring results continue to indicate that the three potential impacts of primary concern (decreased oxygen; accumulation of contaminants; and particulate deposition that smothers the benthos) have not occurred at the MWRA stations. Results also continue to demonstrate that the benthic monitoring program comprises a sensitive suite of parameters that can detect both the influence of the outfall and the subtle natural changes in benthic communities. The spatial extent of particulate deposition from the wastewater discharge is measurable in the *Clostridium perfringens* concentrations in nearfield sediments. *C. perfringens* concentrations provide evidence of the discharge footprint at stations close to the outfall. Within this footprint, no other changes to sediment composition and infaunal communities have been detected. Nonetheless, subtle variations in the species composition of infaunal assemblages clearly delineate natural spatial variation in the benthic community based on habitat (e.g., associated with different sediment grain sizes). Changes over time have also been detected including a region-wide shift towards higher diversity and lower dominance in the Massachusetts Bay infaunal assemblages. Detection of these spatial and temporal patterns in the benthos suggests that any ecologically significant adverse impacts from the outfall would be readily detected by the monitoring program if those impacts had occurred.

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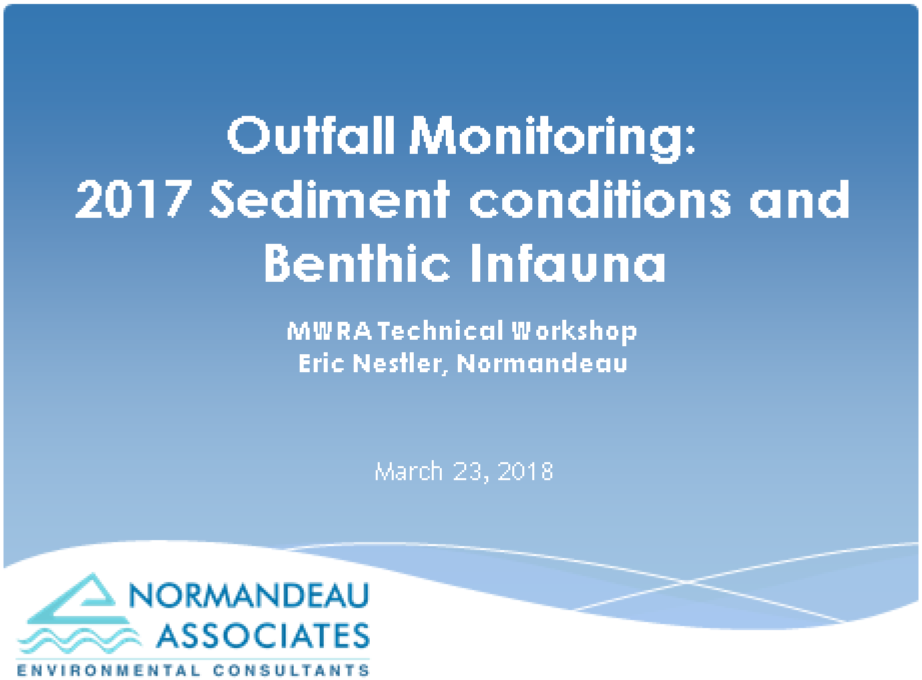
# Appendix A Annual Technical Meeting Presentations for Outfall Benthic Monitoring in 2017

# Appendix A1. 2017 Outfall Monitoring: Sediment Conditions and Benthic Infauna


Outfall Monitoring:
2017 Sediment conditions and Benthic Infauna
MWRA Technical Workshop
Eric Nestler, Normandeau
March 23, 2018
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PRESENTATION OVERVIEW
Massachusetts Bay
• Sediment conditions
– *Clostridium perfringens*, grain size, TOC
– Metals, organics
• Benthic infauna
– Community parameters
– Infaunal assemblages - spatial patterns
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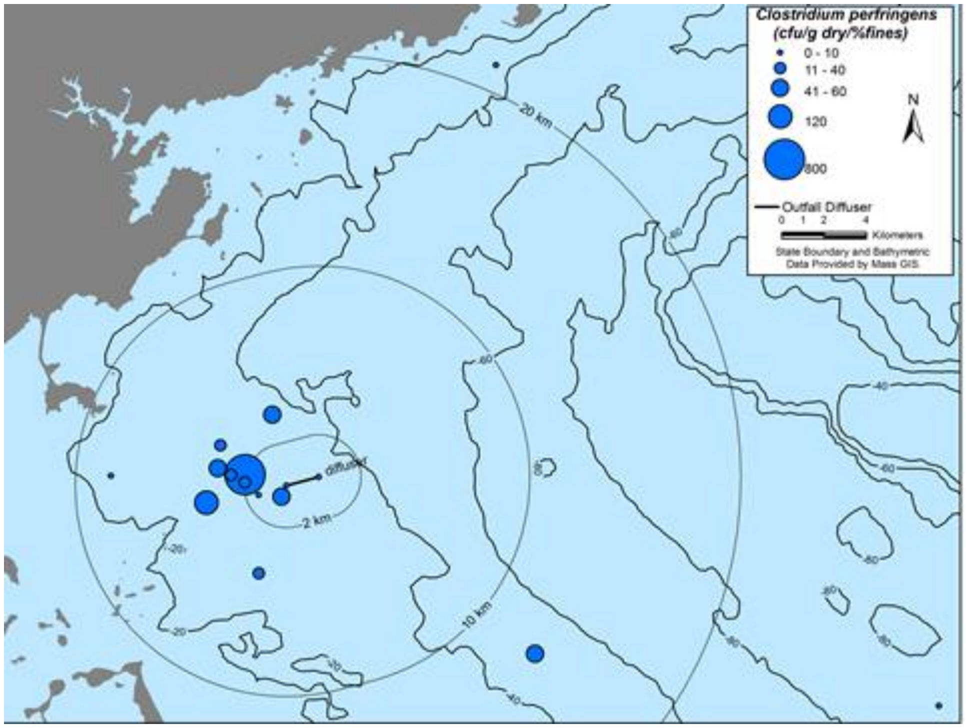
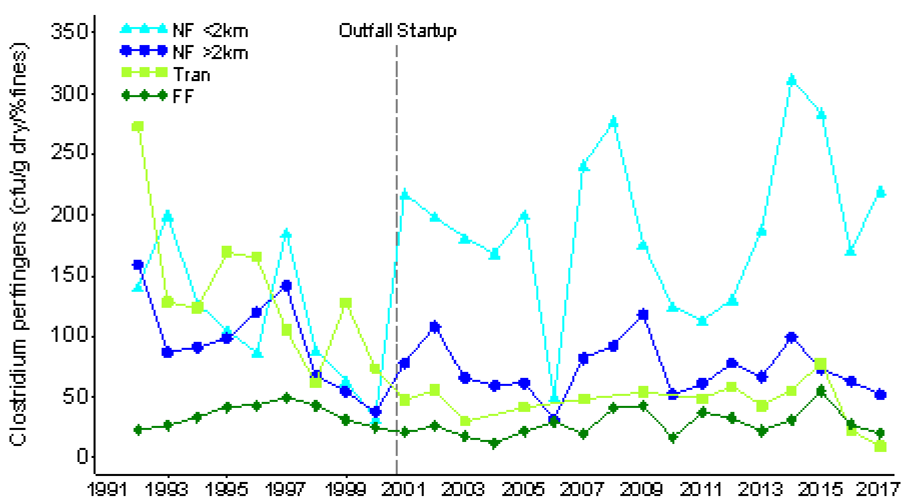
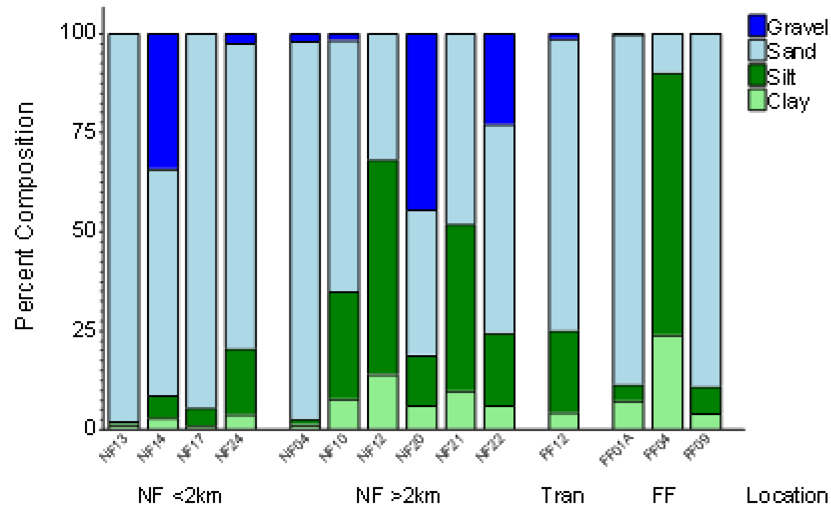


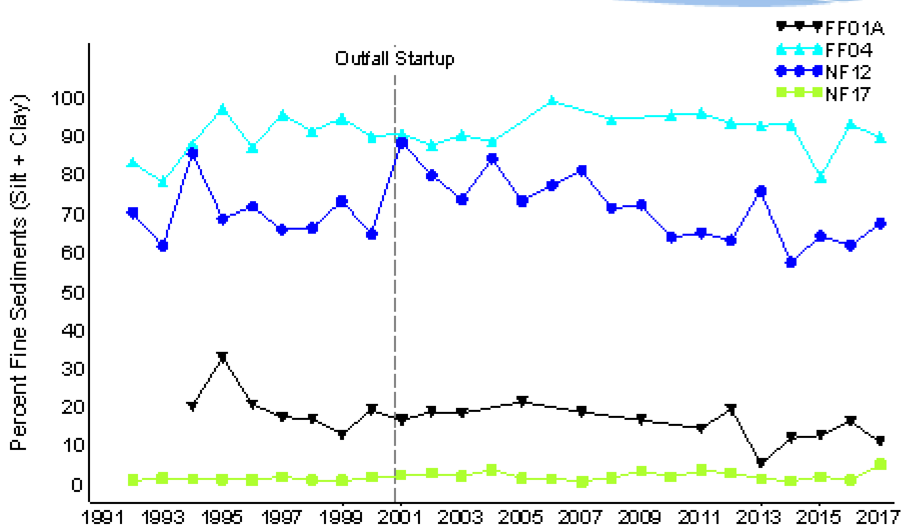

## *Clostridium perfringens* (BY REGION)

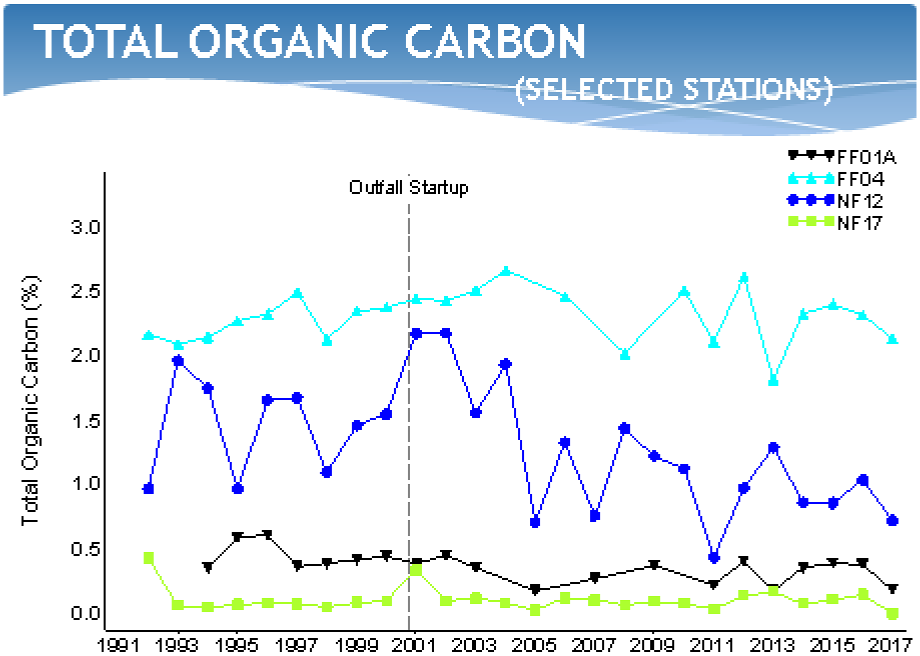


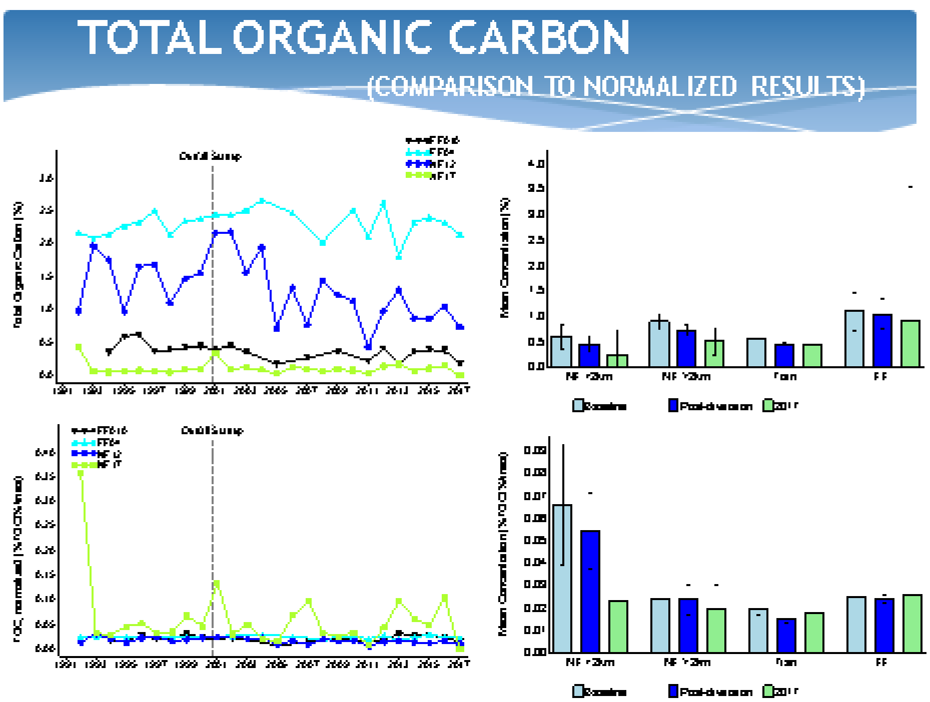
## 2017 SEDIMENT GRAIN SIZE




## PERCENT FINES (SELECTED STATIONS)

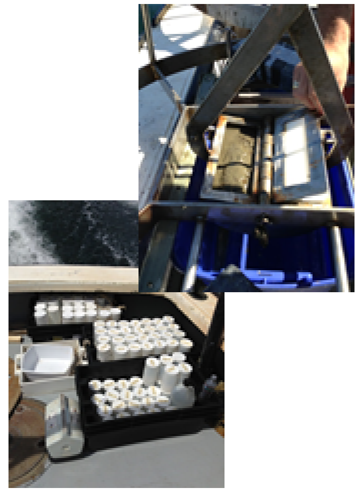



TOTAL ORGANIC CARBON
(SELECTED STATIONS)
FF01A
FF04
NF12
NF17
Outfall Startup
Total Organic Carbon (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017


TOTAL ORGANIC CARBON
(COMPARISON TO NORMALIZED RESULTS)

## MA BAY: SEDIMENT CONTAMINANTS

- No indications of contaminant loading from the outfall.
- No Contingency Plan threshold exceedances for any sediment contaminants in 2017.
  - Thresholds established for 26 toxic pollutants (8 metals and 18 organics).
  - Only 4 out of 26 threshold parameters had mean concentrations above the minimum observed during baseline monitoring (those parameters were well within the baseline range).
- Most contaminant levels have declined.



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## SEDIMENT CONTAMINANTS: SQGs

- Sediment Quality Guidelines (SQGs)
  - ER-M = Effects Range Median: Effects frequently occur.
  - ER-L = Effects Range Low : Effects occasionally occur.
- No contaminant values exceeded ER-Ms in 2017

2017 contaminant values that exceeded ER-Ls

| | Nearfield (≤2 km from outfall) | | | | | Farfield | Sediment Quality Guidelines (SQGs) | |
|---|---|---|---|---|---|---|---|---|
| Parameter | NF10 | NF12 | NF20 | NF21 | NF22 | FF04 | ER-L | ER-M |
| Mercury | 0.15 | 0.40 | 0.19 | 0.35 | 0.17 | 0.20 | 0.15 | 0.71 |
| Nickel | | | | | | 30.2 | 20.9 | 51.6 |
| Total PAH | | 8305 | 5043 | 8370 | | | 4022 | 44792 |

Highest reported value in 2017

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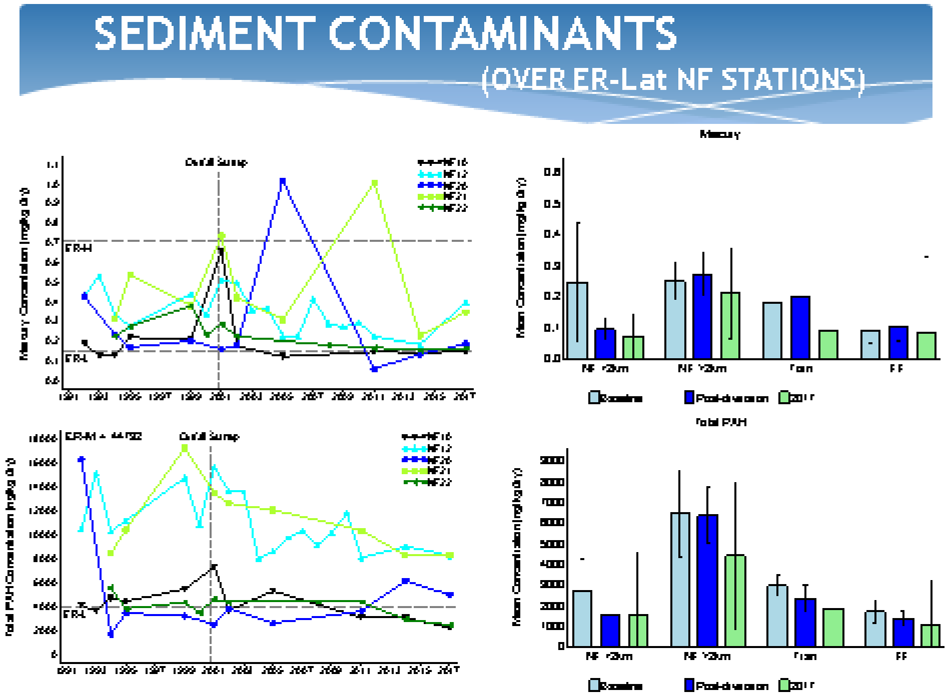
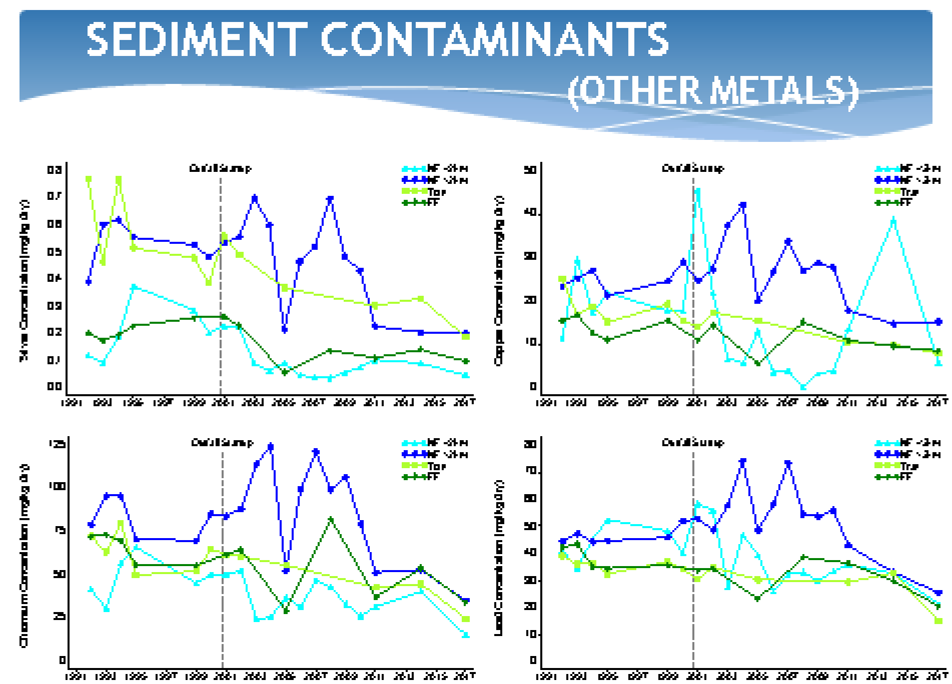
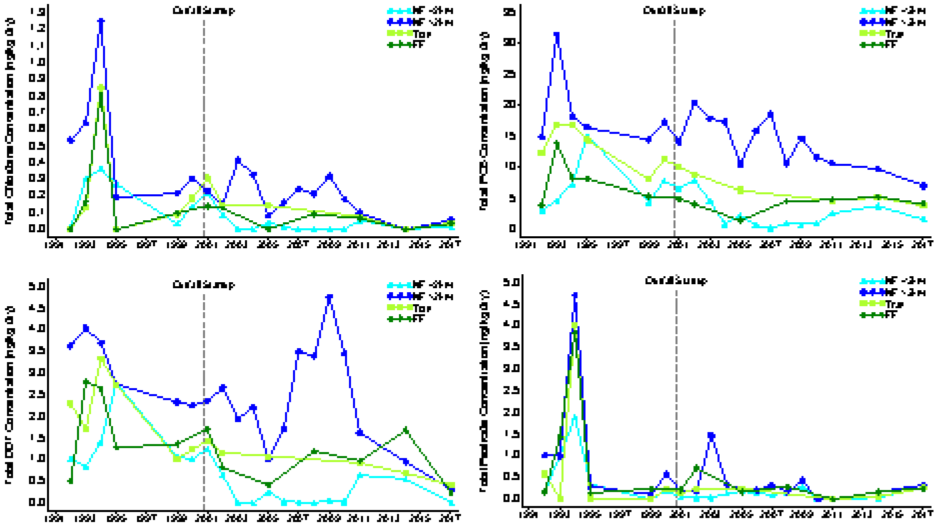

SEDIMENT CONTAMINANTS
(OVER ER-L at NF STATIONS)
Mercury
Total PAH
Outfall Startup
ER-M
ER-L
NF16
NF12
NF24
NF21
NF22
Baseline
Post-diversion
2017


SEDIMENT CONTAINMENTS
(OTHER METALS)
Outfall Startup

## SEDIMENT CONTAMINANTS (OTHER ORGANICS)



## MASSACHUSETTS BAY: BENTHIC INFAUNA

- Totals for 14 samples in 2017:
  - 23,038 individual organisms (18,077 in 2016)
  - 214 taxa identified; 188 species and 26 higher taxonomic groups (196 taxa total and 175 species in 2016)
  - All counts used for abundance
  - Only species-level counts used for diversity measures and multivariate analyses

Source:
http://graysreef.noaa.gov/science/expeditions/2012_nancy_foster1/shell.html

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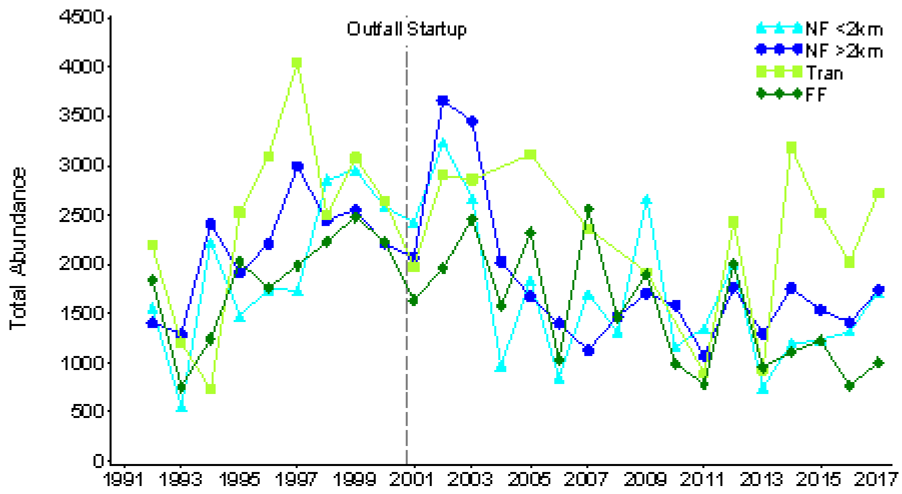
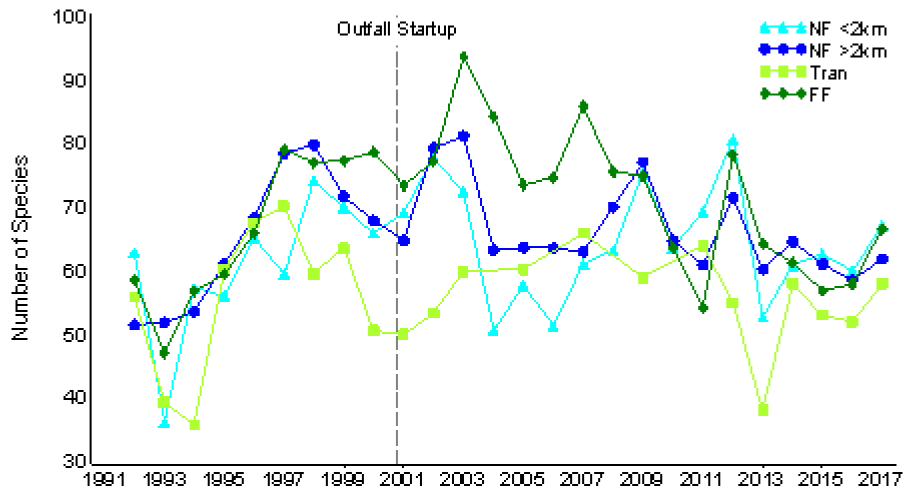
## TOTAL ABUNDANCE (BY REGION)

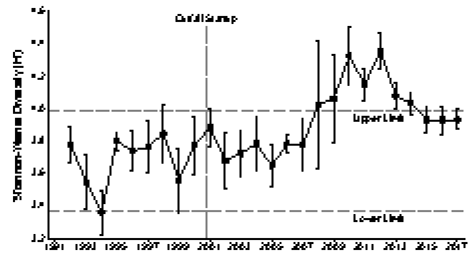


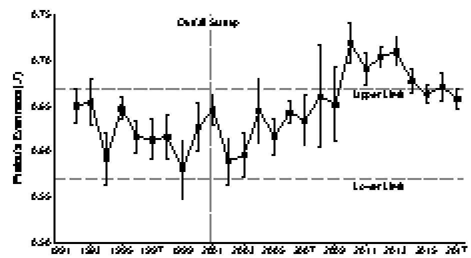

## NUMBER OF SPECIES (BY REGION)



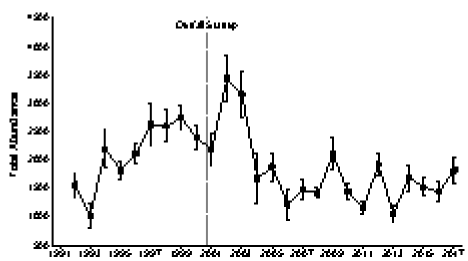
## CONTINGENCY PLAN THRESHOLDS:
### (NF STATIONS ONLY)

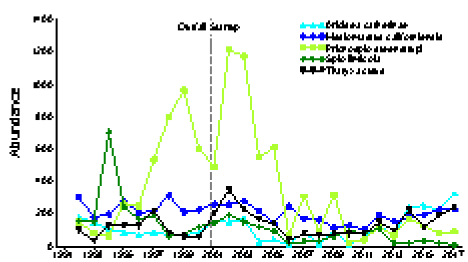
- No exceedances in 2017 for: H', J', total species, log-series alpha, or percent opportunists.
- Exceedances for Shannon-Wiener Diversity (H') and Pielou's Evenness (J') were reported each year from 2010 to 2014.
- February 15, 2018: EPA approved Contingency Plan modification to remove upper level diversity thresholds.





## INFAUNAL COMMUNITY PARAMETERS
### (and DOMINANT SPECIES)





- Total infaunal abundance is largely driven by a few numerically dominant species.
- *Prionospio steenstrupi* was the top dominant in most years from 1996 to 2007.

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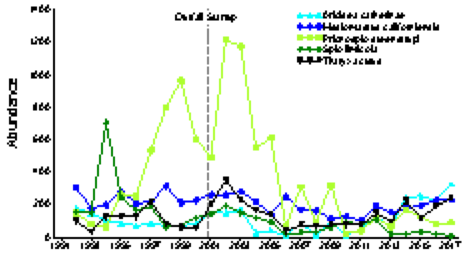
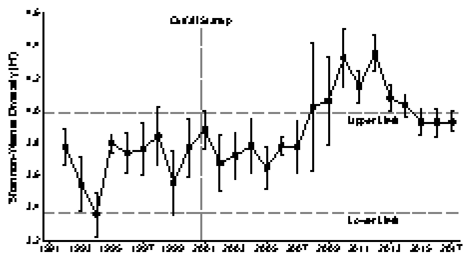
## INFAUNAL COMMUNITY PARAMETERS (and DOMINANT SPECIES)





- Lower numbers of *Prionospio steenstrupi* resulted in higher diversity.

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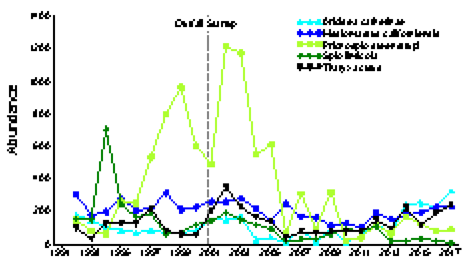
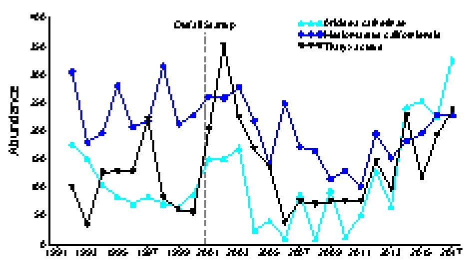
## INFAUNAL COMMUNITY PARAMETERS (and DOMINANT SPECIES)





- *Prionospio steenstrupi* abundances have remained relatively low since 2010.
- Abundances of several other dominant species have been increasing since 2010.

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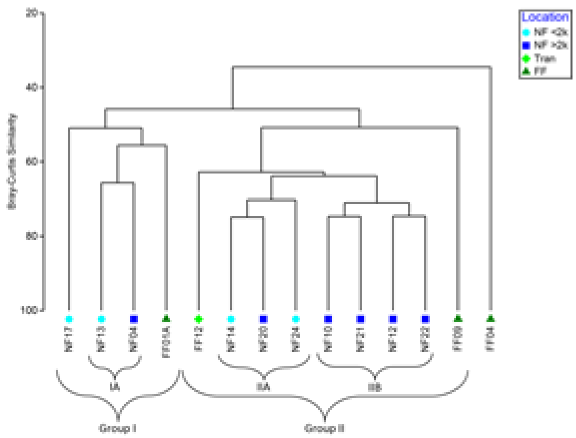
## 2017 INFAUNAL ASSEMBLAGES

### MASSACHUSETTS BAY




- Cluster Analysis:
  - Assess spatial patterns in the distribution of faunal assemblages
  - 2017 Samples
  - Bray-Curtis Similarity

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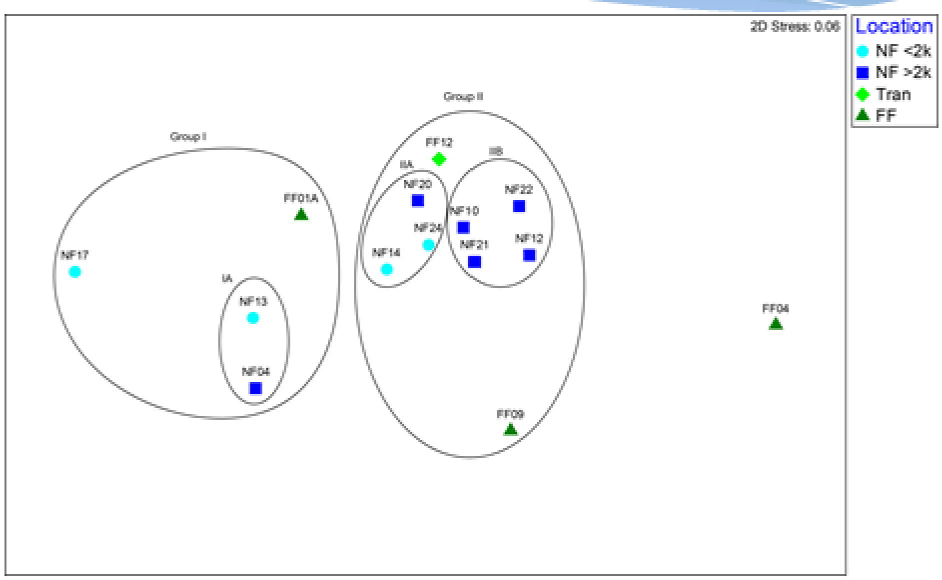
## ORDINATION PLOT: 2017 SAMPLES

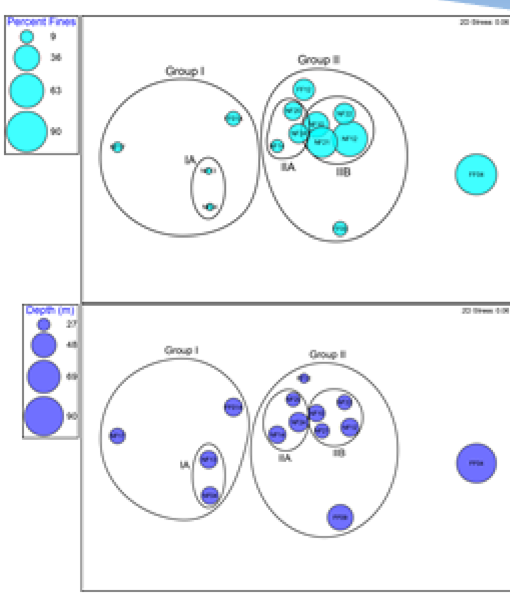
### LOCATION OVERLAY



## 2017 INFAUNAL ASSEMBLAGES
### MASSACHUSETTS BAY

- Group IA: NF04, NF13 (sand)
  - *Aricidea catherinae, Tharyx acutus, Exogone hebes*
- Group I outliers: NF17, FF01A (sand)
  - *Spiophanes bombyx, Polygordius jouinae, Kirkegaardia baptisteae*
- Group IIA: NF14, NF20 , NF24 (sand with fines, gravel)
  - *A. catherinae, Mediomastus californiensis, T. acutus*
- Group IIB: NF10, NF12, NF21, NF22 (fines with sand)
  - *M. californiensis, T. acutus, K. baptisteae*
- Group II outliers: FF12, FF09 (sand, some fines; FF09 is deeper)
  - *A. catherinae, T. acutus, , K. Baptisteae, Anobothrus gracilis, Nucula delphinodonta, Levinsenia gracilis*
- FF04 (fines; deepest)
  - *L. gracilis, Cossura longocirrata, Chaetozone anasimus*

## 2017 INFAUNAL ASSEMBLAGES
### MASSACHUSETTS BAY




- Faunal distributions reflect habitat
  - Sediment grain size
  - Depth
  - Hydrodynamic conditions

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## MASSACHUSETTS BAY: SUMMARY

- Sediment conditions
  - Plume footprint indicated by *Clostridium perfringens*; only at stations closest to the outfall.
  - No evidence of change in grain size or TOC from the discharge.
  - Sediment contaminant levels continue to decline; all 26 parameters for threshold comparisons were within or below baseline levels in 2017.
- Benthic infauna
  - Faunal distributions reflect habitat (e.g., sediment grain size).
  - No threshold exceedances in 2017. Upper level infaunal diversity thresholds have been dropped.
  - No evidence of impacts to infauna from the discharge.

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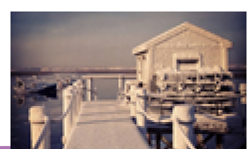
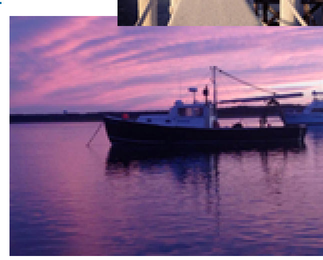
## ACKNOWLEDGEMENTS

- Massachusetts Water Resources Authority
  - Ken Keay (Program Manager)
- Normandeau Associates, Inc.
  - Hannah Proctor (Laboratory Manager), Erik Fel'Dotto (Field Manager)
- Cove Corporation
- Ocean's Taxonomic Services





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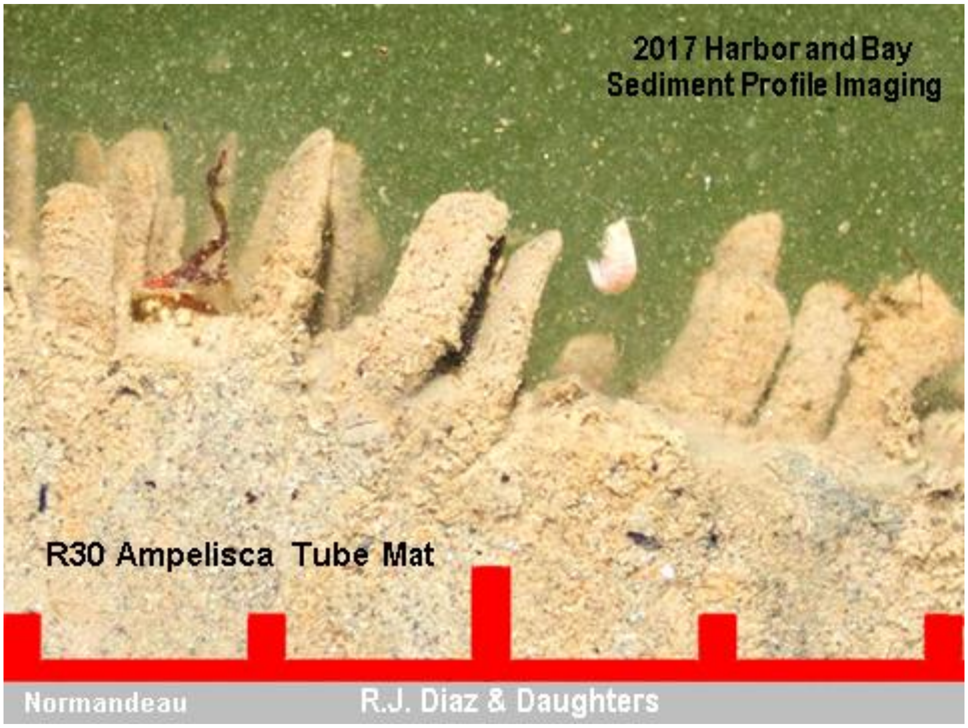
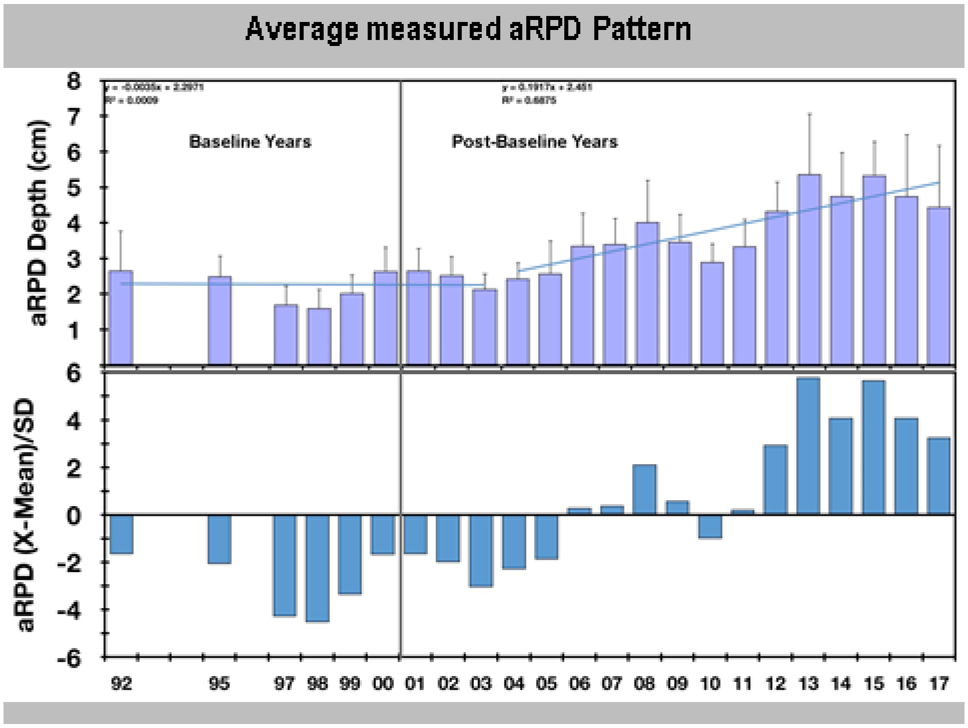
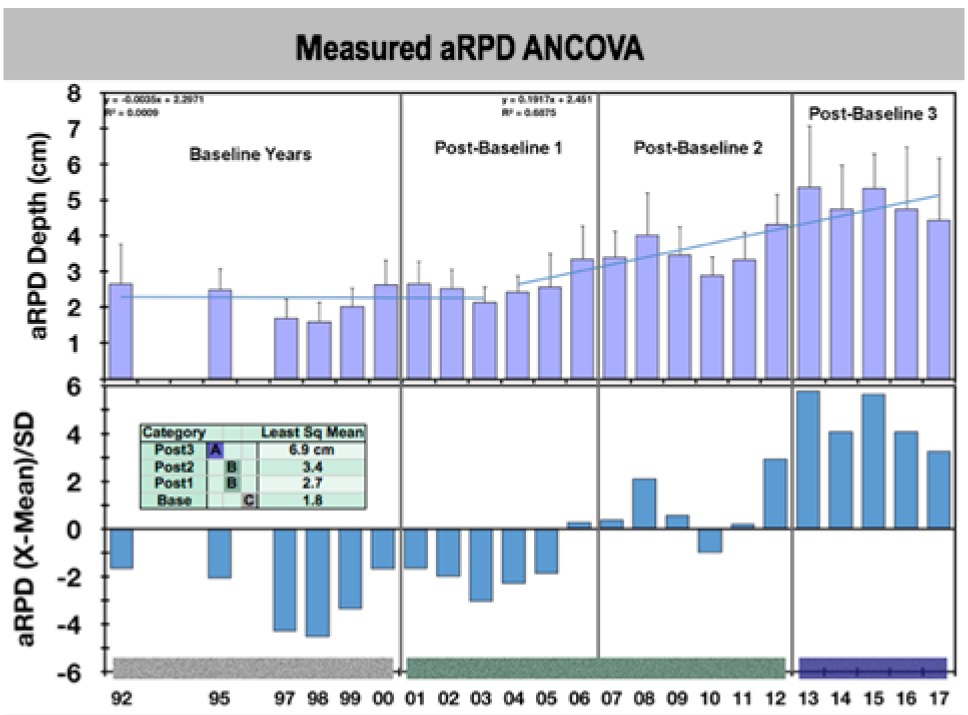
# Appendix A2. 2017 Harbor and Bay Sediment Profile Imaging

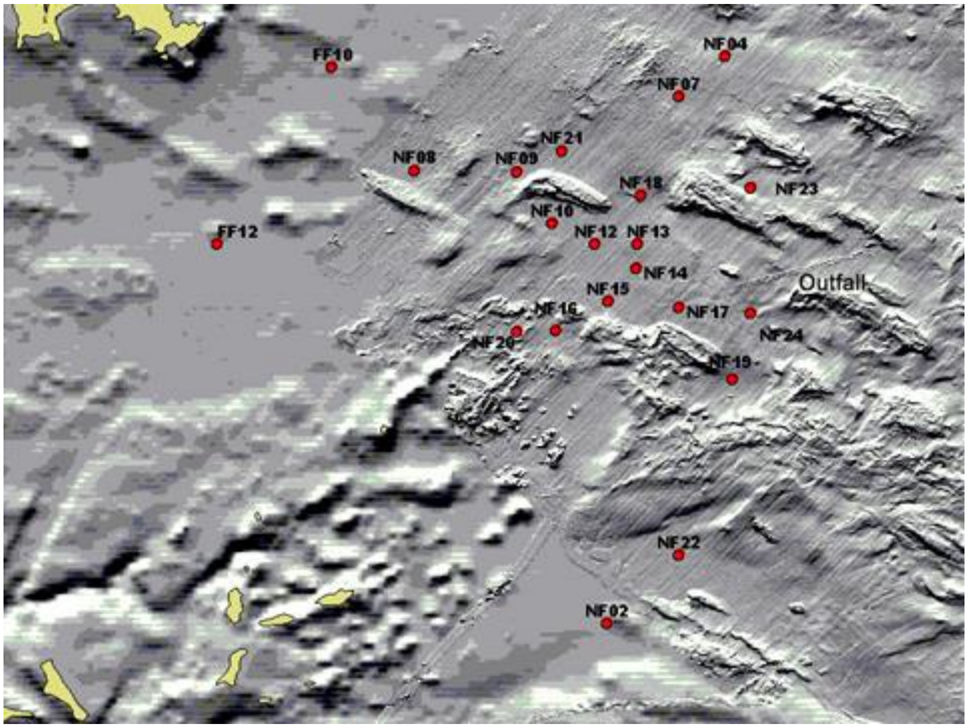


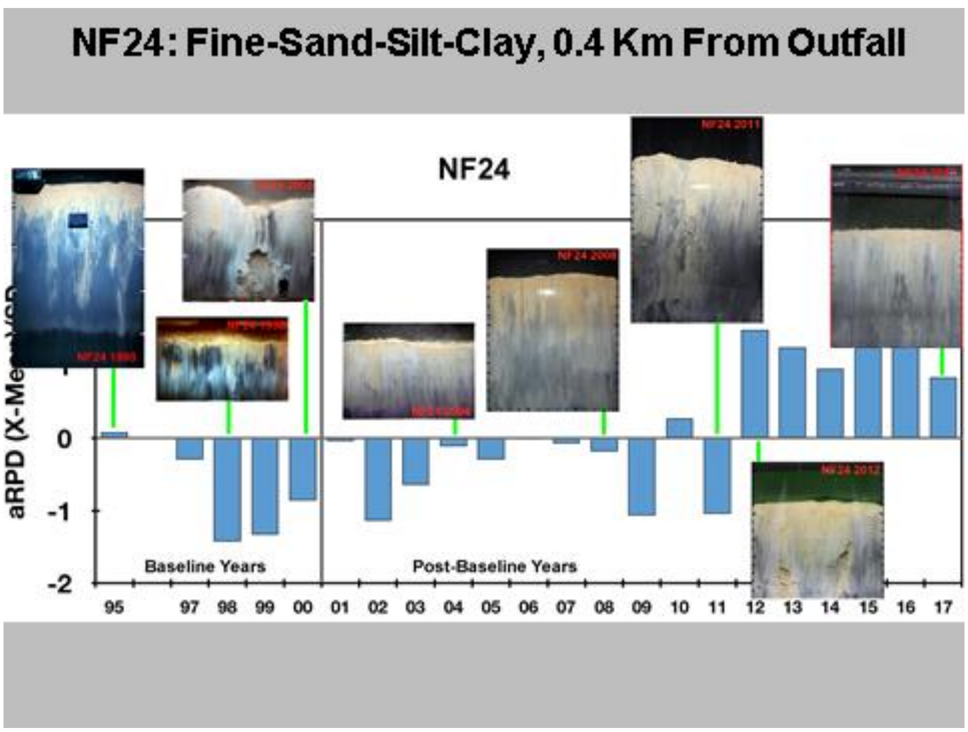

## Nearfield Summary
## Baseline vs. Post-Baseline

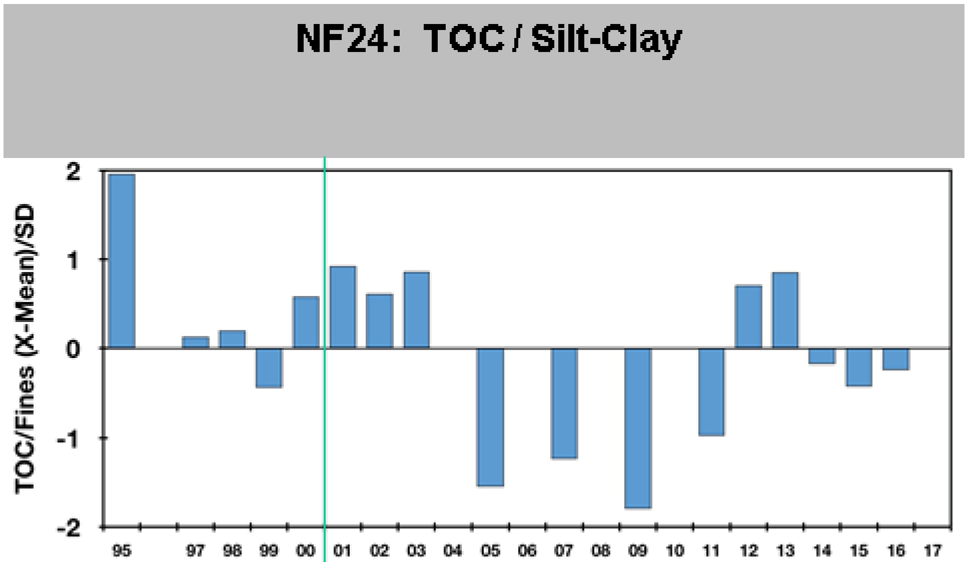
| | Baseline Years 1992-2000 9-Year Interval | Post-Baseline Years 2001-2017 16-Year Interval | Only 2017 |
|---|---|---|---|
| SS | Advanced from I to II-III | Bimodal: II-III tending to I | Bimodal: I-II and I |
| OSI - Low | 4.8 (1997) | 5.8 (2003) | |
| OSI - High | 7.2 (2000) | 8.7 (2012) | 8.0 (N = 21) |
| RPD - Low | 1.8 cm (1997 and 1998) | 2.1 cm (2003) | |
| RPD -High | 3.0 cm (1995) | 5.5 cm (2015) | |
| Annual Mean RPD Measured | 2.2 (0.48 SD) cm | 3.6 (1.05 SD) cm | 4.4 (1.14 SD) cm N = 14 |
| Annual Mean RPD All Values | 2.4 (0.47 SD) cm | 3.2 (0.87 SD) cm | 4.2 (1.33 SD) cm N = 23 |


Average measured aRPD Pattern
y = -0.0035x + 2.2971
R² = 0.0009
y = 0.1917x + 2.451
R² = 0.6875
Baseline Years
Post-Baseline Years
aRPD Depth (cm)
aRPD (X-Mean)/SD
92 95 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17

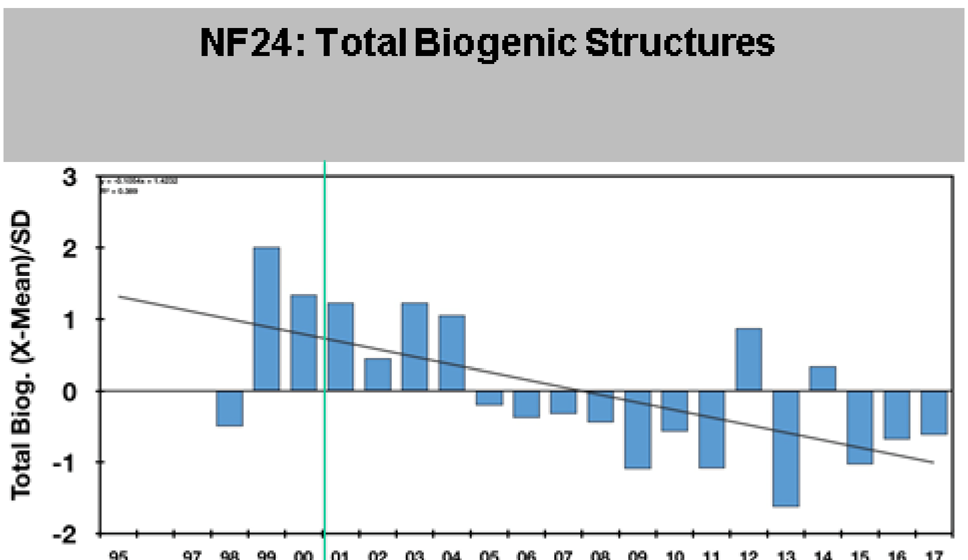

Measured aRPD ANCOVA
y = -0.0035x + 2.2971
R² = 0.0009
y = 0.1917x + 2.451
R² = 0.6875
Baseline Years
Post-Baseline 1
Post-Baseline 2
Post-Baseline 3
aRPD Depth (cm)
aRPD (X-Mean)/SD
Category Least Sq Mean
Post3 A 6.9 cm
Post2 B 3.4
Post1 B 2.7
Base C 1.8
92 95 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17


FF10
NF04
NF07
NF21
NF08
NF09
NF18
NF23
NF10
FF12
NF12
NF13
NF14
Outfall
NF15
NF16
NF17
NF20
NF24
NF19
NF22
NF02

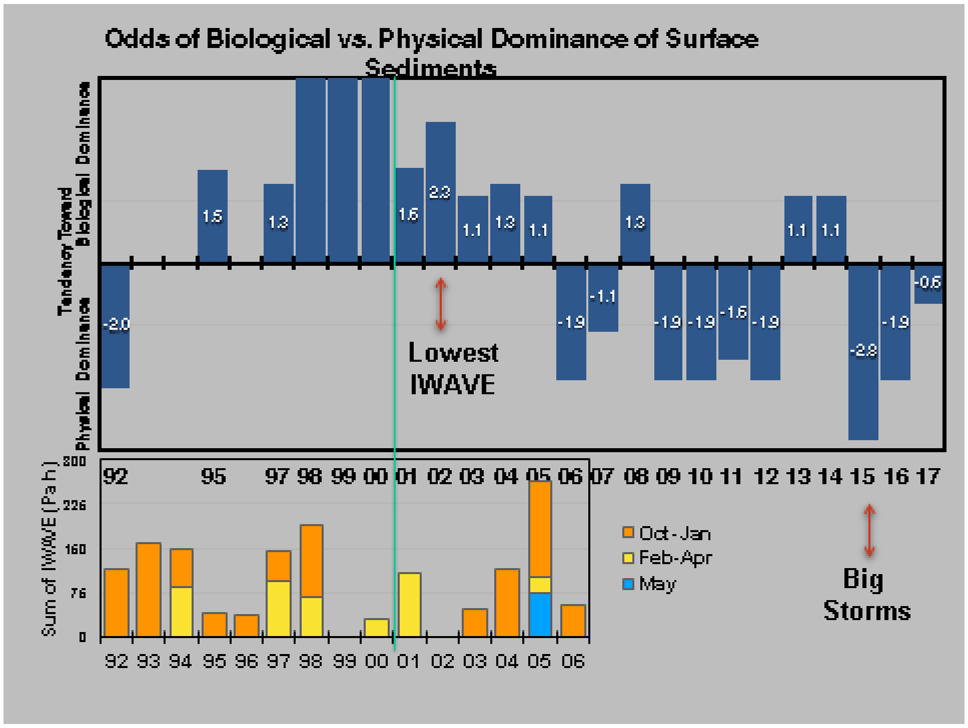

NF24: Fine-Sand-Silt-Clay, 0.4 Km From Outfall
NF24
aRPD (X-Mean VGD)
0
-1
-2
Baseline Years
Post-Baseline Years
95
97
98
99
00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
NF24 2011
NF24 2008
NF24 2012

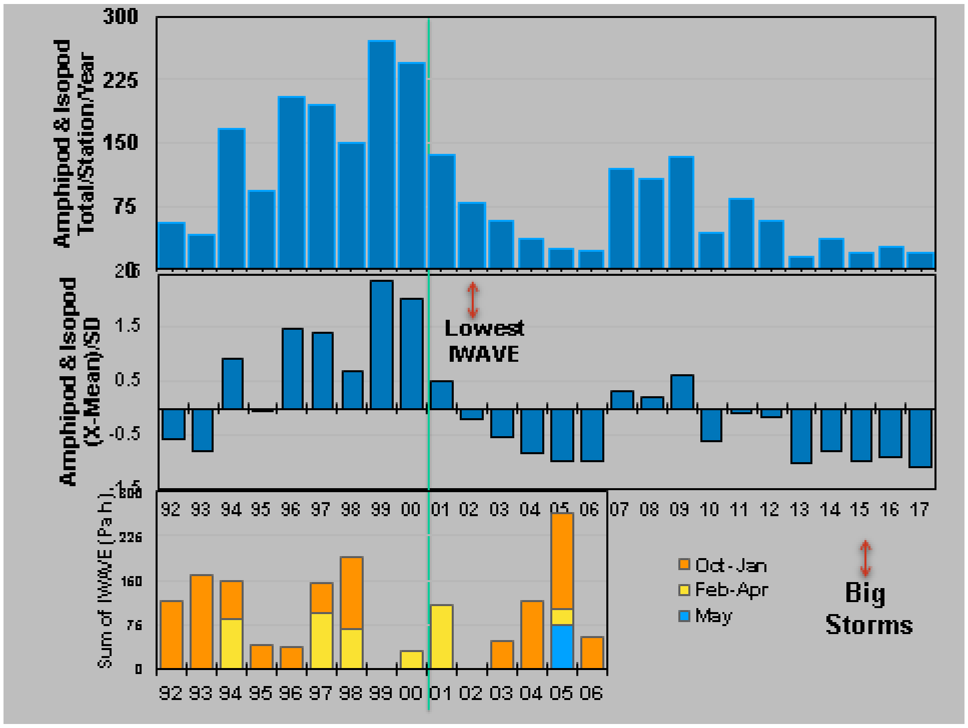


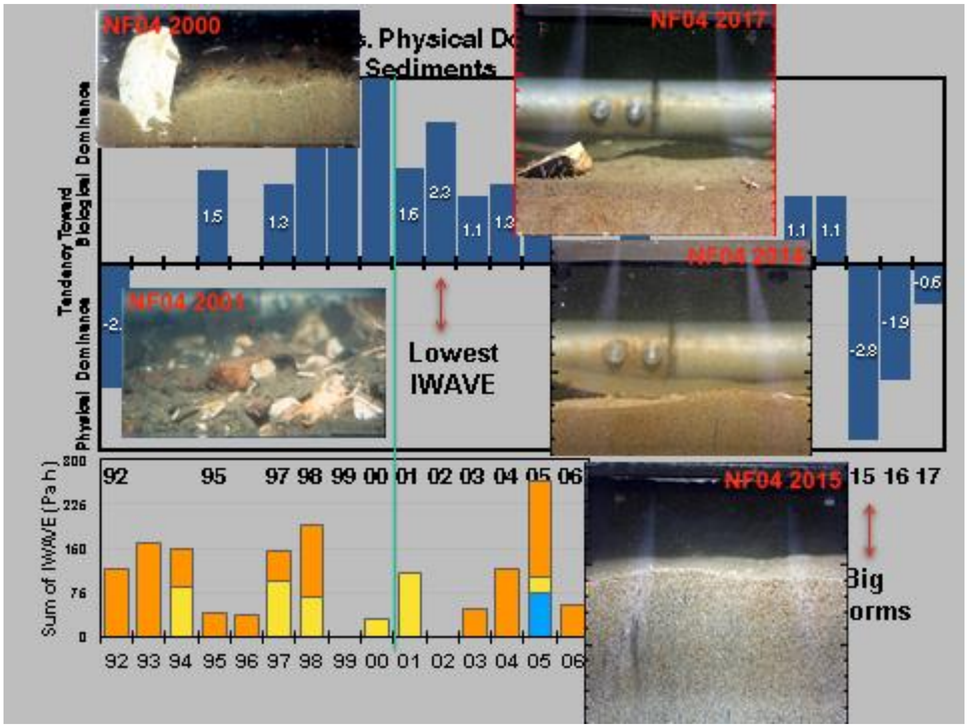

| Year | 95 | | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | 2.8 | | 1.5 | 0.6 | 1.1 | 1.3 | 1.2 | 1.1 | 1.1 | | 0.6 | | 0.5 | | 0.5 | | 0.7 | 1.4 | 1.8 | 0.4 | 0.9 | 0.4 | |

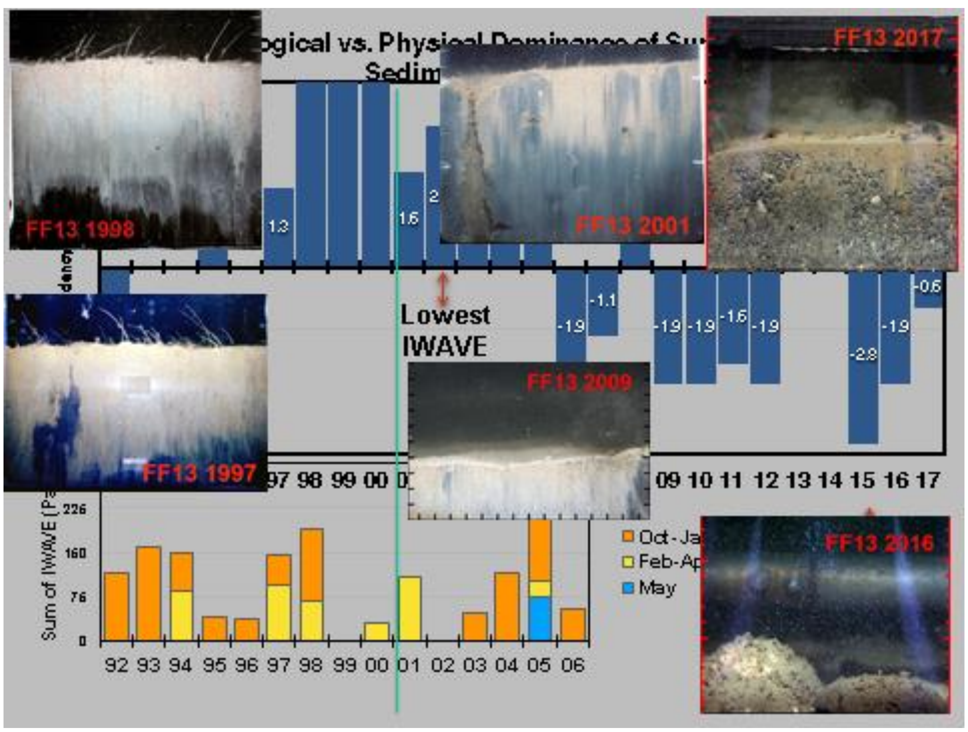



| Year | 95 | | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Biog | | | | 7 | 21 | 17 | 17 | 12 | 17 | 16 | 9 | 8 | 8 | 7 | 4 | 7 | 4 | 15 | 1 | 12 | 4 | 6 | 6 |


Odds of Biological vs. Physical Dominance of Surface Sediments
Tendency Toward Biological Dominance
Physical Dominance
Lowest IWAVE
Sum of IWAVE (Pa h)
Oct-Jan
Feb-Apr
May
Big Storms


Amphipod & Isopod Total/Station/Year
Amphipod & Isopod (X-Mean)/SD
Lowest IWAVE
Sum of IWAVE (Pa h)
Oct-Jan
Feb-Apr
May
Big Storms


NF04 2000
NF04 2017
NF04 2001
NF04 2016
NF04 2015
Sediments
Tendency Toward Biological Dominance
Physical Dominance
Lowest IWAVE
Sum of IWAVE (Pa h)
92 93 94 95 96 97 98 99 00 01 02 03 04 05 06
15 16 17

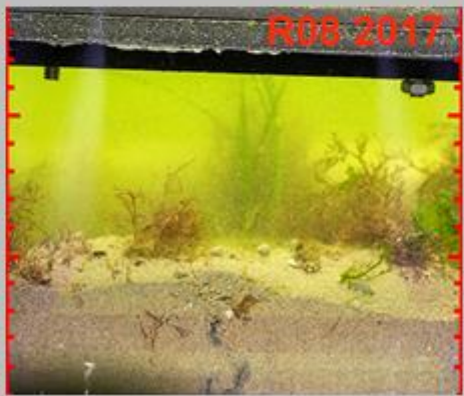

FF13 1998
FF13 2017
FF13 2001
FF13 1997
FF13 2009
FF13 2016
Lowest IWAVE
Oct-Ja
Feb-Ap
May
92 93 94 95 96 97 98 99 00 01 02 03 04 05 06
09 10 11 12 13 14 15 16 17

## Nearfield 2017 Summary

- Regional shift from biological to physical dominance of surface sediments coincident with diversion. Trend over last several years is for return of biological dominance.
- aRPD Post-Baseline continues to be deeper than Baseline.
- Benthic habitat quality characteristics remained similar through time.
- Sediments appeared about the same as 2016.

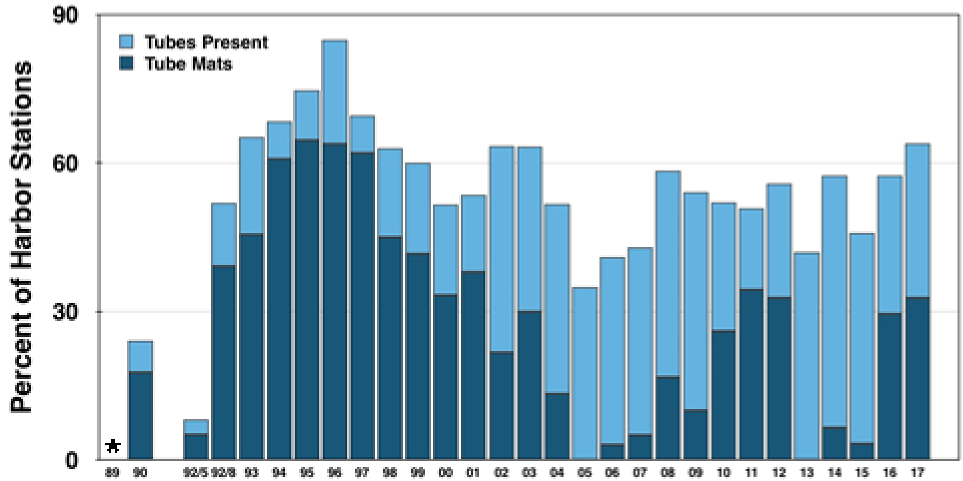
## Harbor for 2017

- Eel grass bed at R08 on Deer Island Flats, $10^{th}$ year.
- Large amounts of macroalgae for 3rd year.

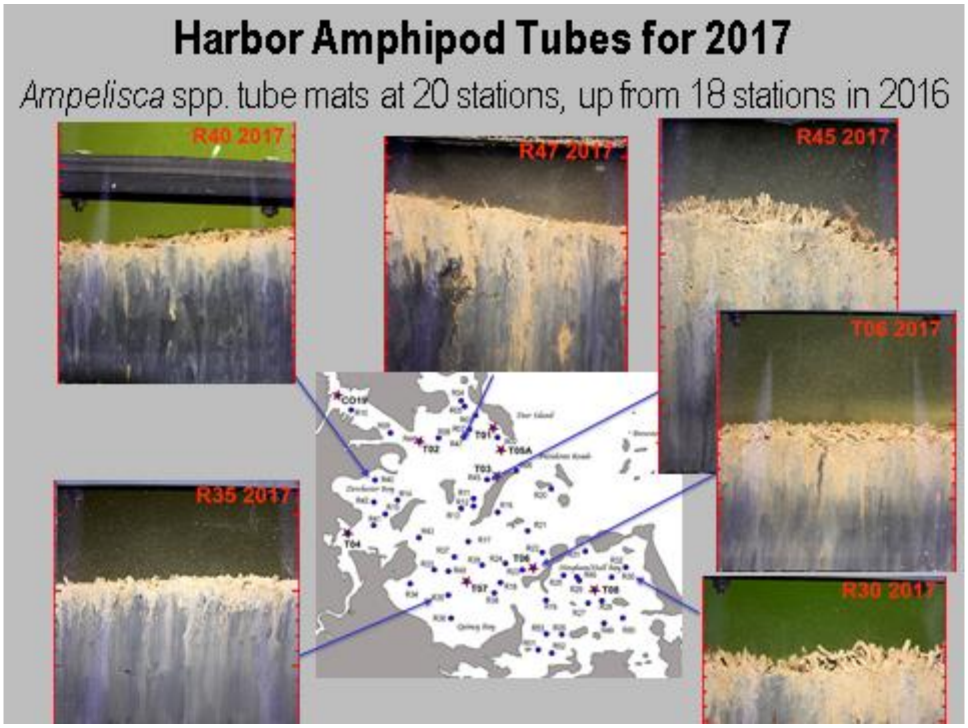
## Harbor Amphipod Tubes for 2017

*Ampelisca* spp. tube mats at 20 stations

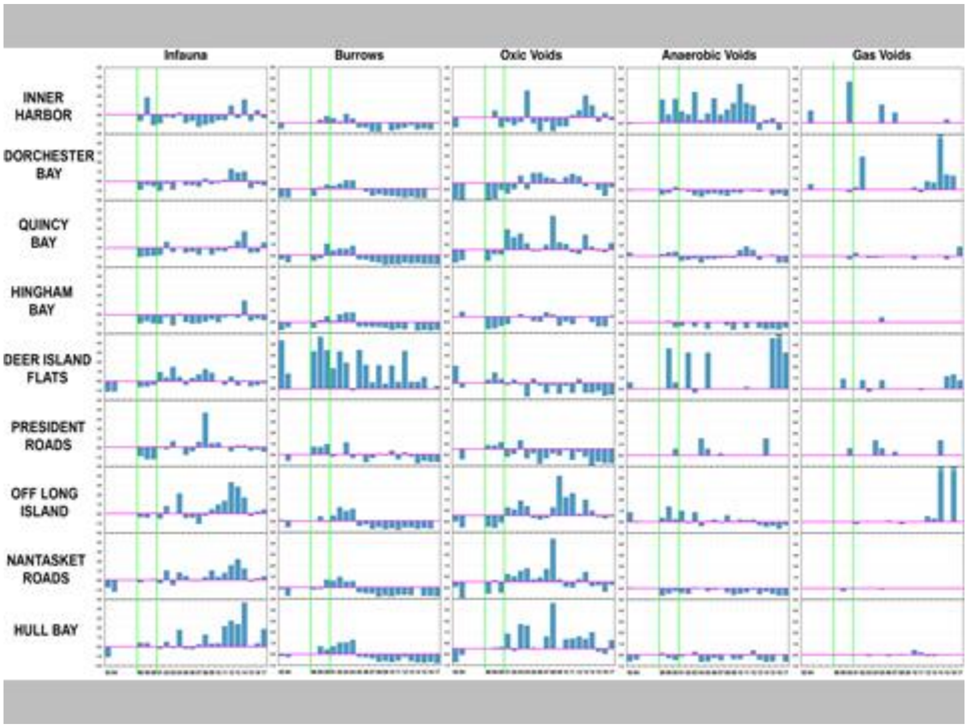



* SPI collected by SAIC in 1989 did not appear to have *Ampelisca* tubes, but live mussel beds and long thin tubes were present at may stations in high densities.

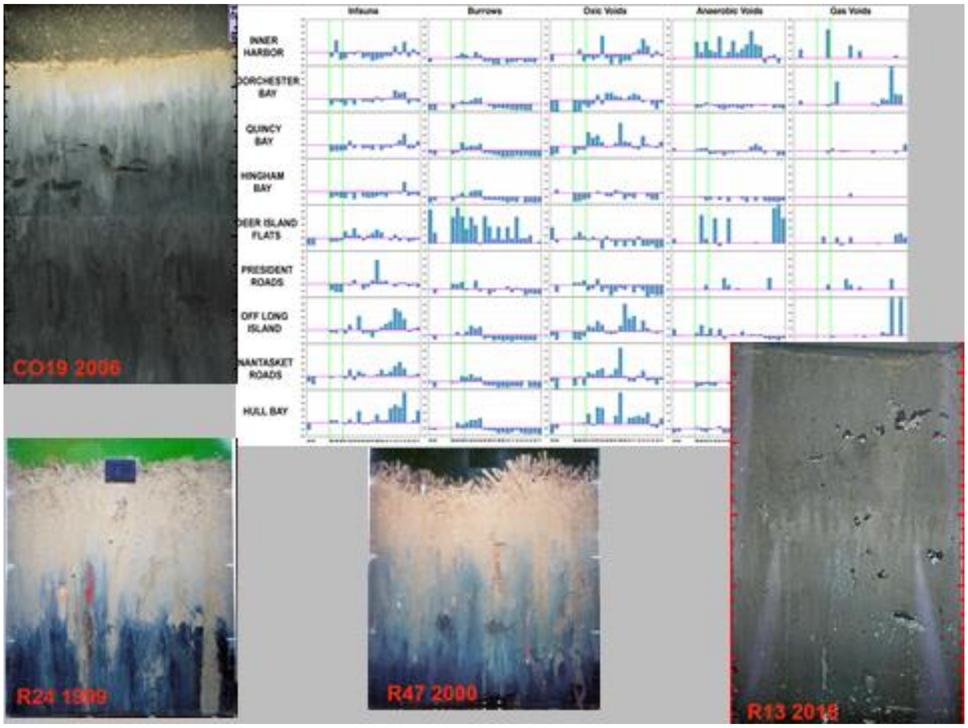
**54 (near R20) June 1989 - SAIC**

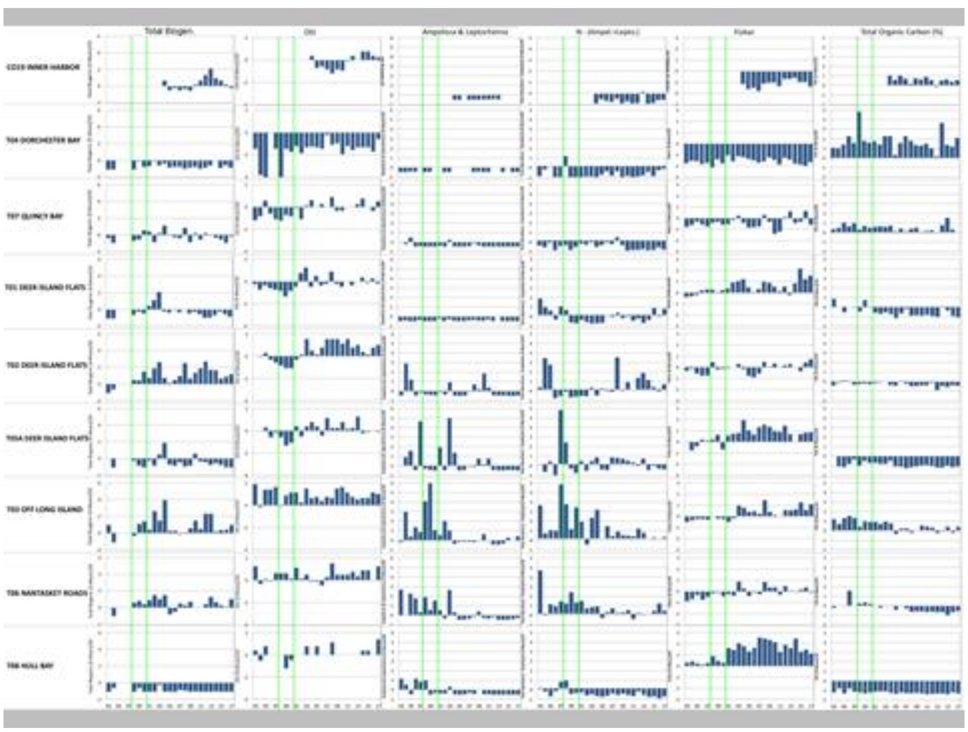


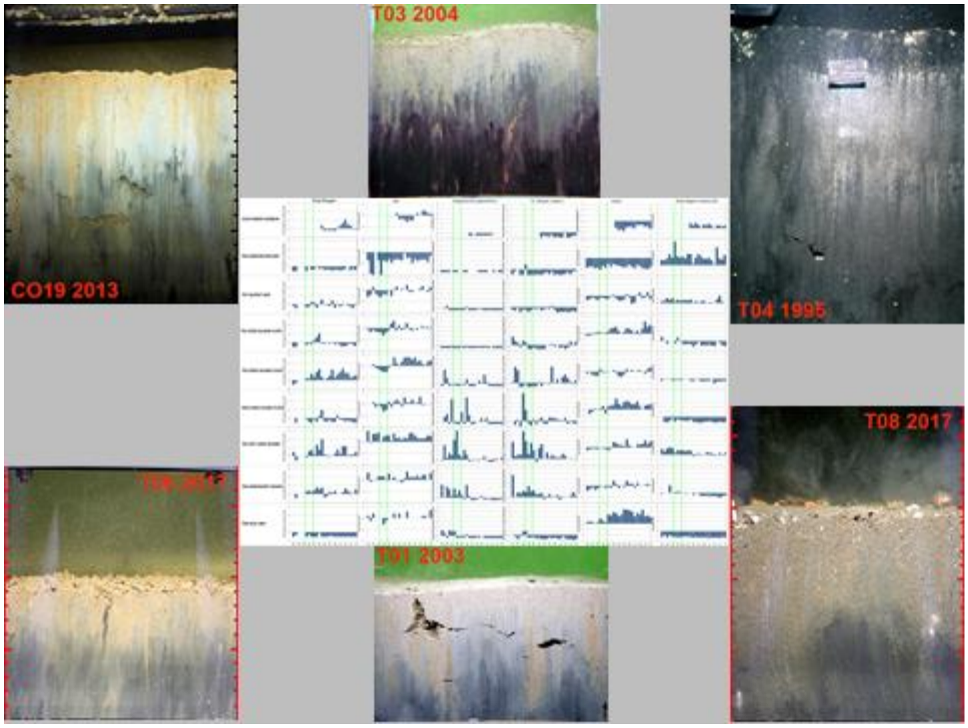
Harbor Amphipod Tubes for 2017
*Ampelisca* spp. tube mats at 20 stations, up from 18 stations in 2016
R40 2017
R47 2017
R45 2017
T06 2017
R35 2017
R30 2017

Infauna
Burrows
Oxic Voids
Anaerobic Voids
Gas Voids
INNER HARBOR
DORCHESTER BAY
QUINCY BAY
HINGHAM BAY
DEER ISLAND FLATS
PRESIDENT ROADS
OFF LONG ISLAND
NANTASKET ROADS
HULL BAY


Infauna
Burrows
Oxic Voids
Anaerobic Voids
Gas Voids
INNER HARBOR
DORCHESTER BAY
QUINCY BAY
HINGHAM BAY
DEER ISLAND FLATS
PRESIDENT ROADS
OFF LONG ISLAND
NANTASKET ROADS
HULL BAY
CO19 2006
R24 1999
R47 2000





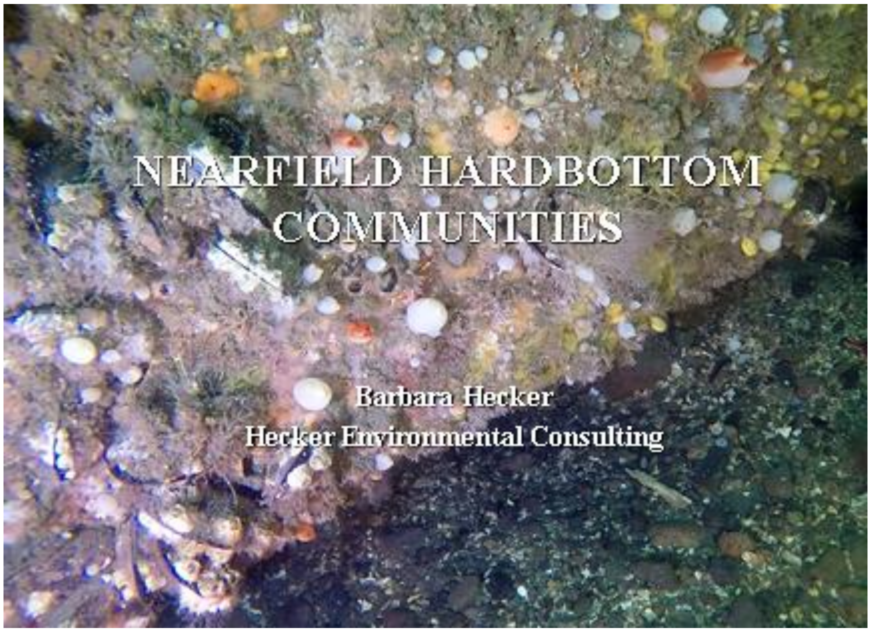

## Summary for Harbor 2017

Benthic habitat quality for infauna trended higher in all Harbor regions, except Inner Harbor.

Inner to outer harbor gradient remains prominent and related:

- Primarily to hydrodynamics
- Secondarily to sediment grain-size and organic matter content

# Appendix A3. 2017 Nearfield Hard-Bottom Communities


NEARFIELD HARDBOTTOM
COMMUNITIES
Barbara Hecker
Hecker Environmental Consulting


• Benthic communities inhabiting hard-bottom drumlins vicinity of the outfall
• Complementary to soft-bottom studies
• Has the hard-bottom community changed?


Acknowledgements
Field and Lab
Normandeau - Debbie Rutecki
Ocean Eye - Bill Campbell
BlackLaser Learning - Vince Capone
CR Environmental - Chip Ryther, Eli Peron, Adrianna Ortiz, Joshua Goodwin
Boat Kathleen A. Mirarchi, Inc. - Frank Mirarchi
Battelle - Jeannine Boyle, Robert Mandiville
SAIC/ENSR/AECOM - Brigitte Hilbig, Pam Neubert, Paula Winchell
Other
MWRA - Ken Keay, Wendy Leo, Doug Hersh
Normandeau - Ann Pembroke, Eric Nestler
SAIC/ENSR/AECOM - James Blake, Nancy Maciolek
Battelle - Carlton Hunt, Ellie Baptiste-Carpenter


Acknowledgements
Field and Lab
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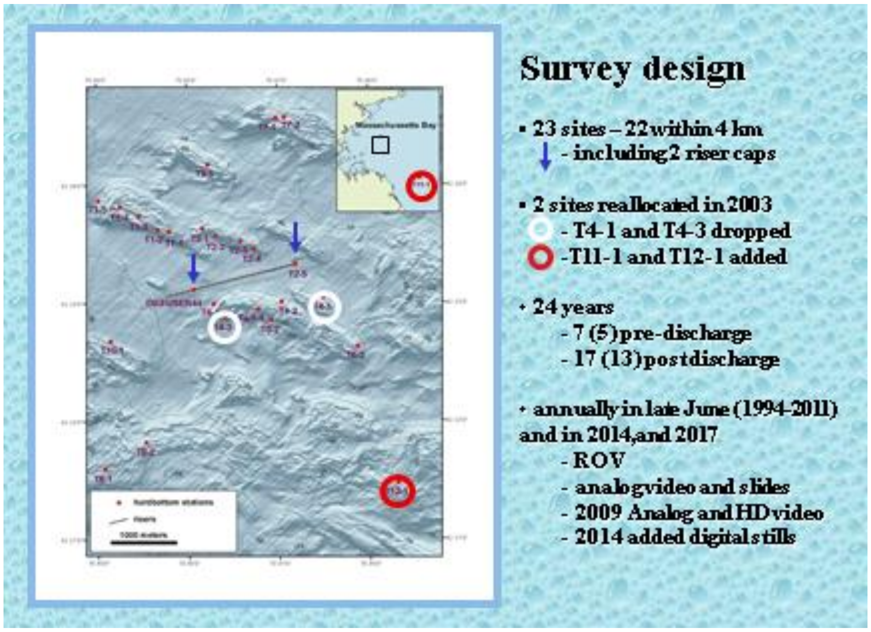
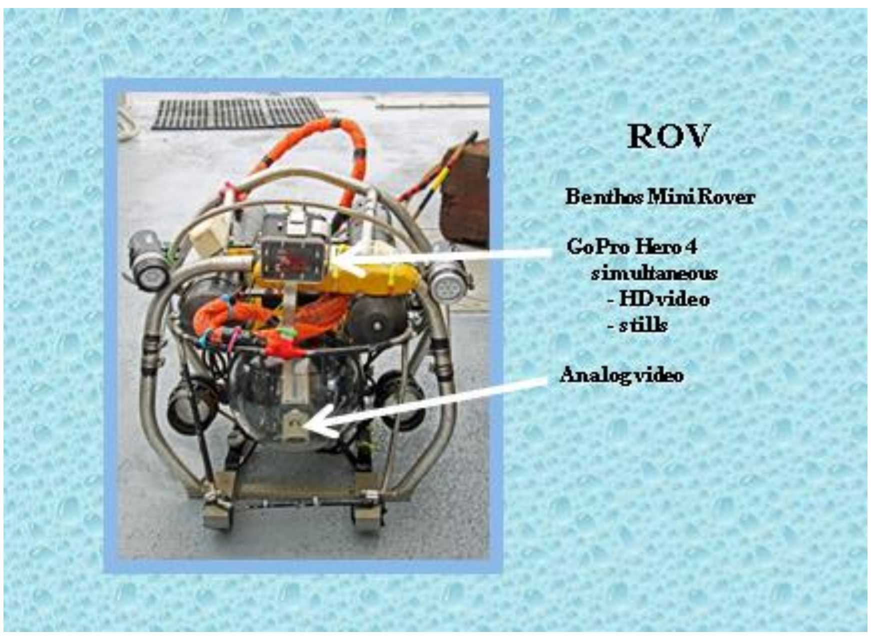
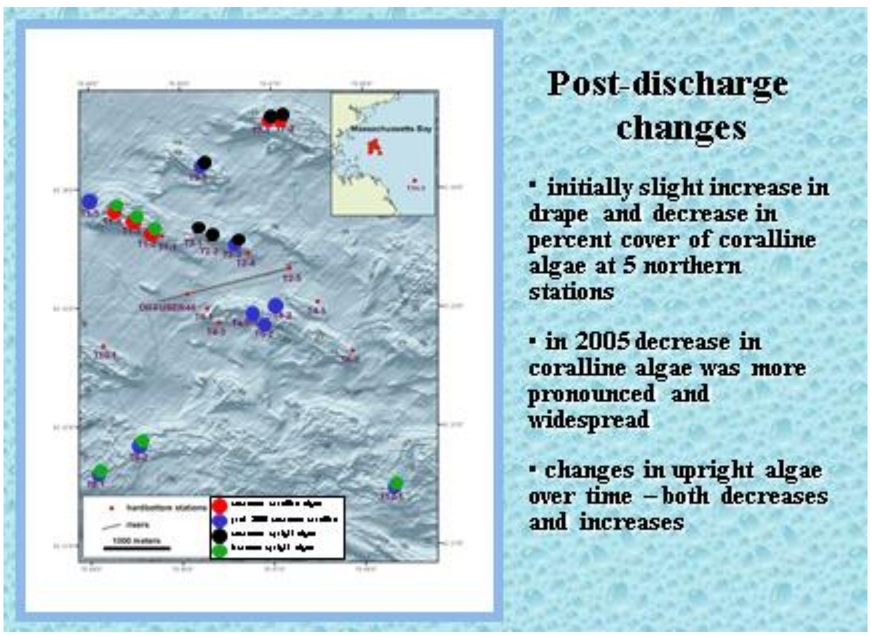
Battelle - Jeannine Boyle, Robert Mandiville
SAIC/ENSR/AECOM - Brigitte Hilbig, Pam Neubert, Paula Winchell
Other
MWRA - Ken Keay, Wendy Leo, Doug Hersh
Normandeau - Ann Pembroke, Eric Nestler
SAIC/ENSR/AECOM - James Blake, Nancy Maciolek
Battelle - Carlton Hunt, Ellie Baptiste-Carpenter


Survey design
• 23 sites – 22 within 4 km
- including 2 riser caps
• 2 sites reallocated in 2003
- T4-1 and T4-3 dropped
-T11-1 and T12-1 added
• 24 years
- 7 (5) pre-discharge
- 17 (13) postdischarge
• annually in late June (1994-2011) and in 2014, and 2017
- ROV
- analog video and slides
- 2009 Analog and HD video
- 2014 added digital stills

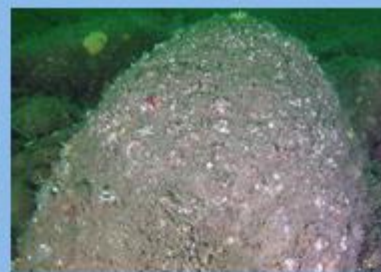

ROV
Benthos Mini Rover
GoPro Hero 4
simultaneous
- HD video
- stills
Analog video


Previous findings
▪ Hard-bottom areas are spatially variable
▪ Biotic communities have remained relatively stable between 1996 and 2014
▪ Some subtle shifts in community structure over time
▪ Post-discharge changes have been relatively modest
▪ Lush growth continues on the active riser
▪ Physical disturbance may be compromising northern reference sites
▪ Data from video less sensitive than from stills and has a lag time

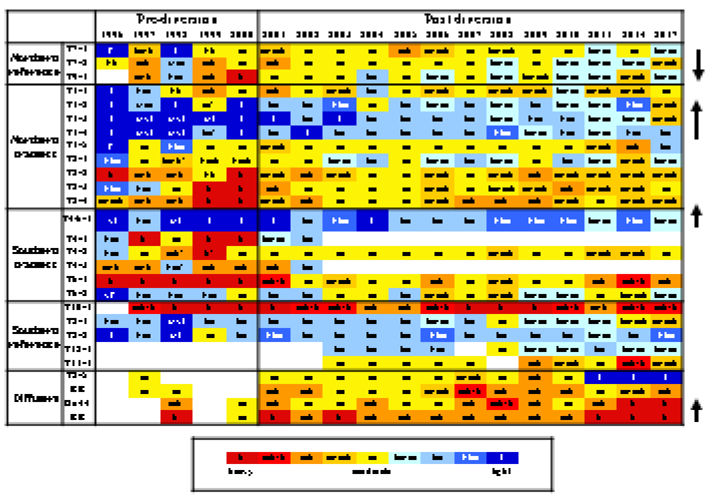

Post-discharge changes
▪ initially slight increase in drape and decrease in percent cover of coralline algae at 5 northern stations
▪ in 2005 decrease in coralline algae was more pronounced and widespread
▪ changes in upright algae over time – both decreases and increases
Massachusetts Bay
DIFFUSER #44
1000 meters

# Drape

- visible layer of detrital material composed of phytodetritus, zooplankton fecal pellets, fine-grained resuspended sediments, biogenic tubes, and effluent particles.
- increase since 2001 at northern drumlin top sites
- hint of an increase at some southern stations since 2005
- related to outfall?
- regional trend?



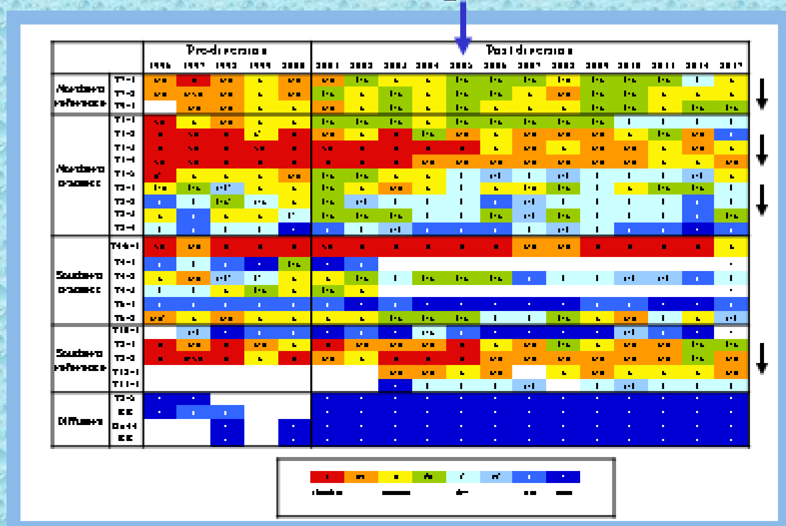
# Drape



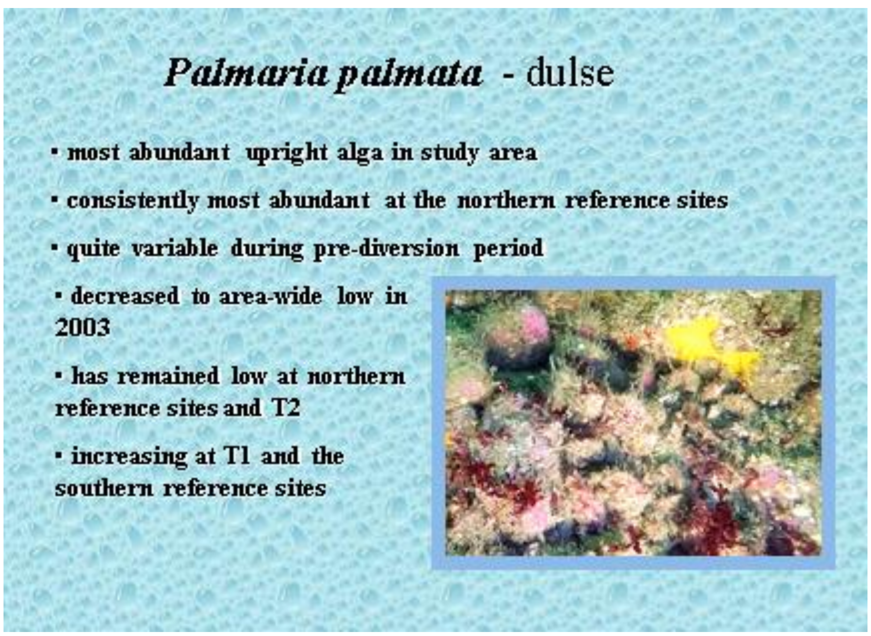
## Coralline algae

- most abundant and consistent biota in study area
- decrease in percent cover since 2001 at northern drumlin top sites in data from 2004
- decrease most pronounced in 2005 and spread south
- related to outfall?
- regional trend?

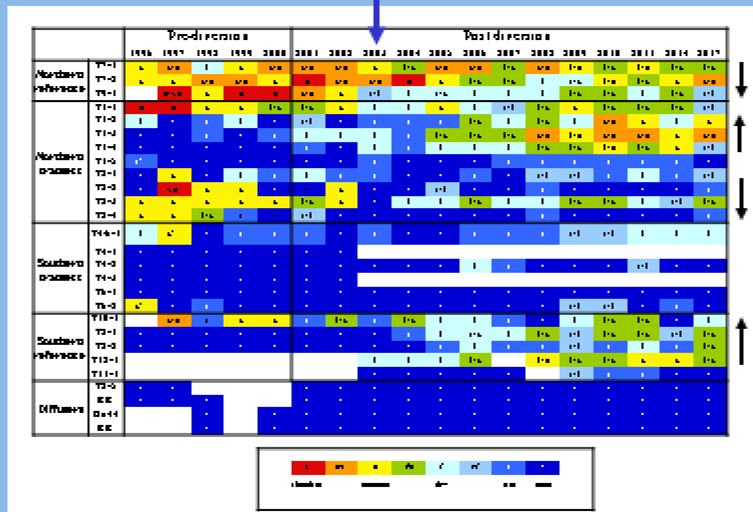
## Coralline algae




Upright algae
• restricted to shallower stations and patchy distributions
• general decrease in abundance over time, now reversing
• initially only abundant at northern reference sites
• last several years seeing some at southern reference sites
• changes appear to be cyclical and not related to the outfall
• physical disturbance may explain some of the decreases at northern reference sites

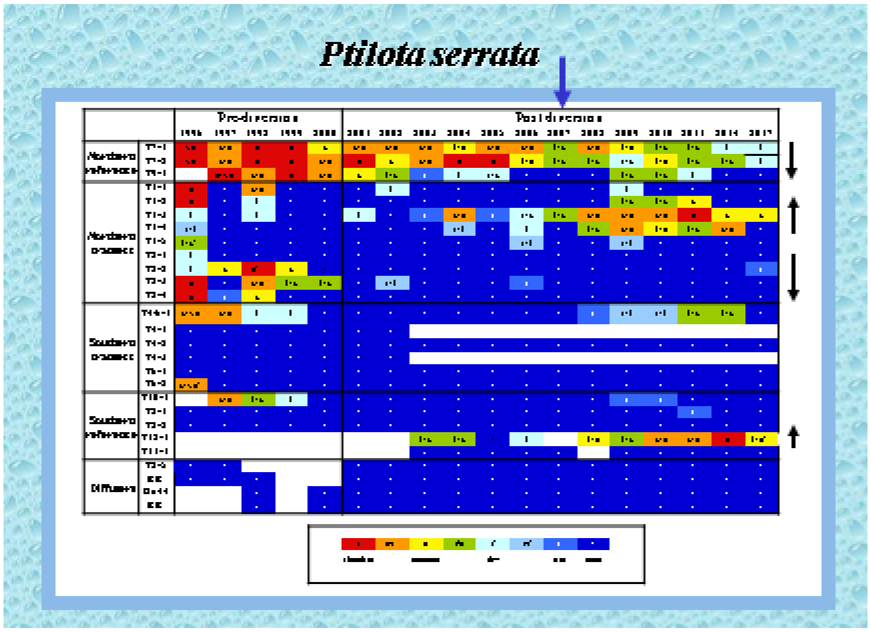

*Palmaria palmata* - dulse
• most abundant upright alga in study area
• consistently most abundant at the northern reference sites
• quite variable during pre-diversion period
• decreased to area-wide low in 2003
• has remained low at northern reference sites and T2
• increasing at T1 and the southern reference sites

## *Palmaria palmata*



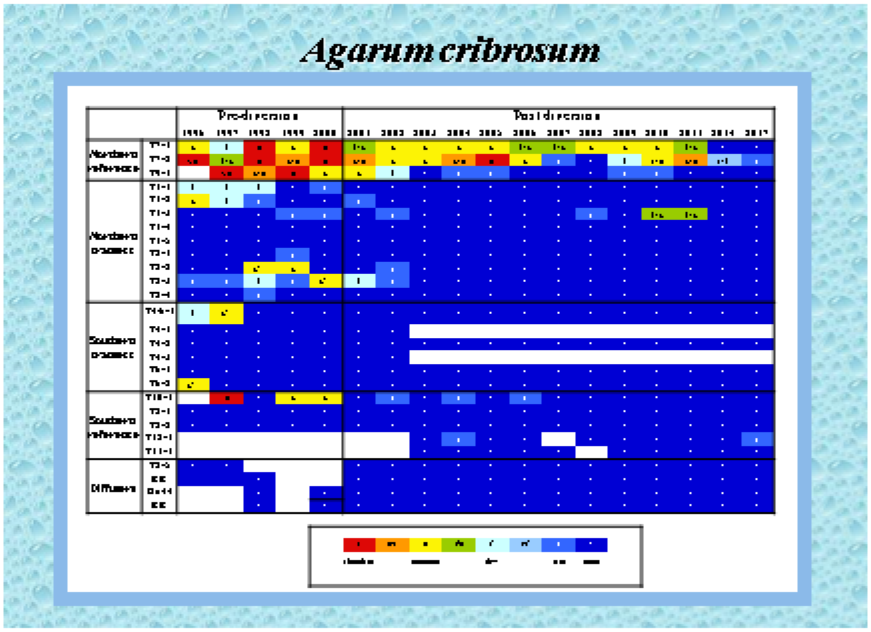

## *Ptilota serrata* - filamentous red alga

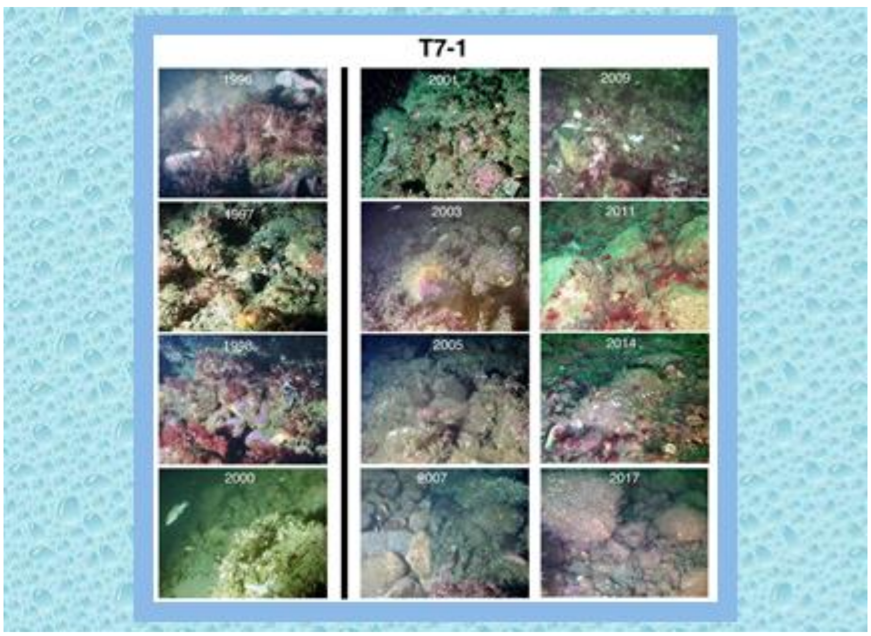
- was only consistently abundant north of the outfall
- general decline over time at the northern reference sites and T2
- no sizable populations were left by 2007
- rebounding at three T1 sites
- appearing at one southern site

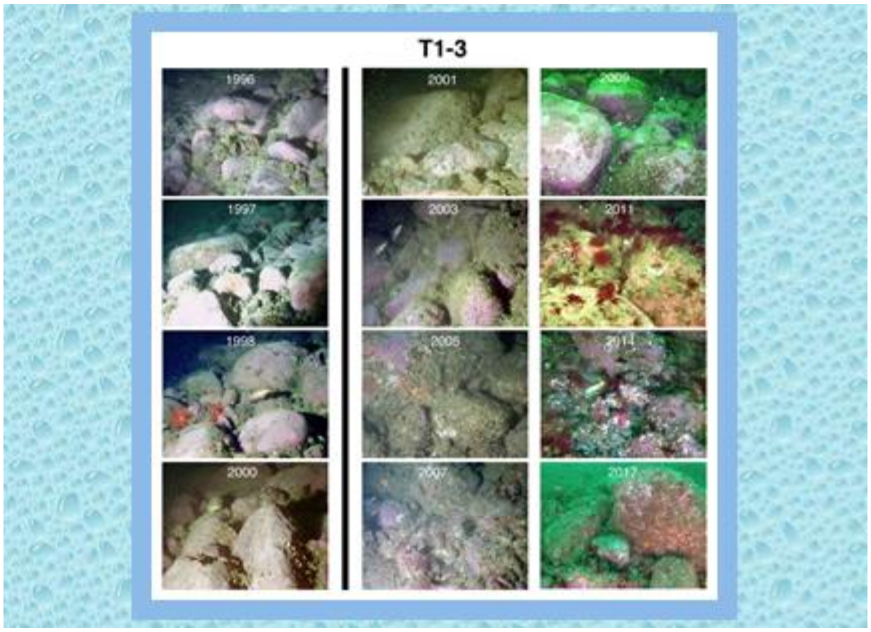


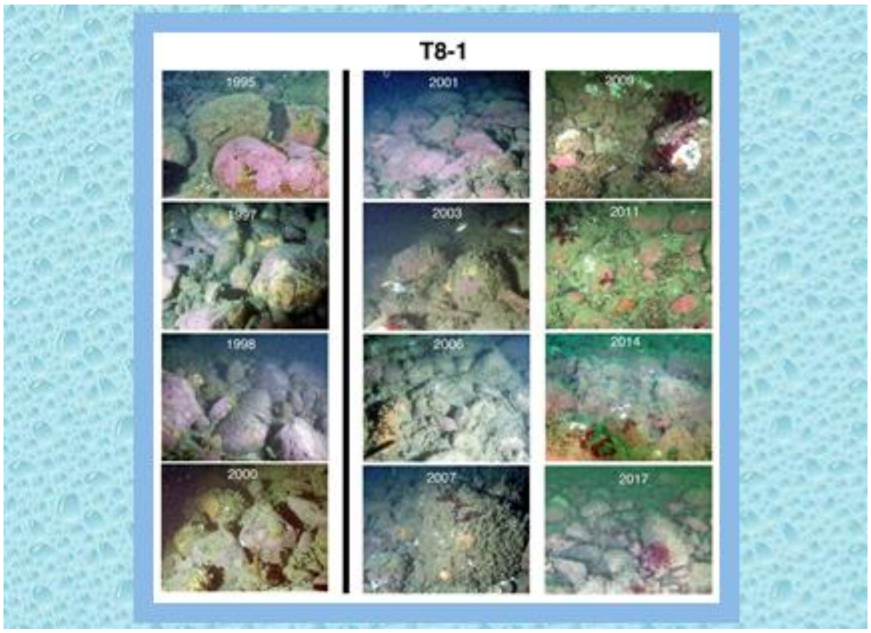

## *Agarum cribrosum* - shotgun kelp

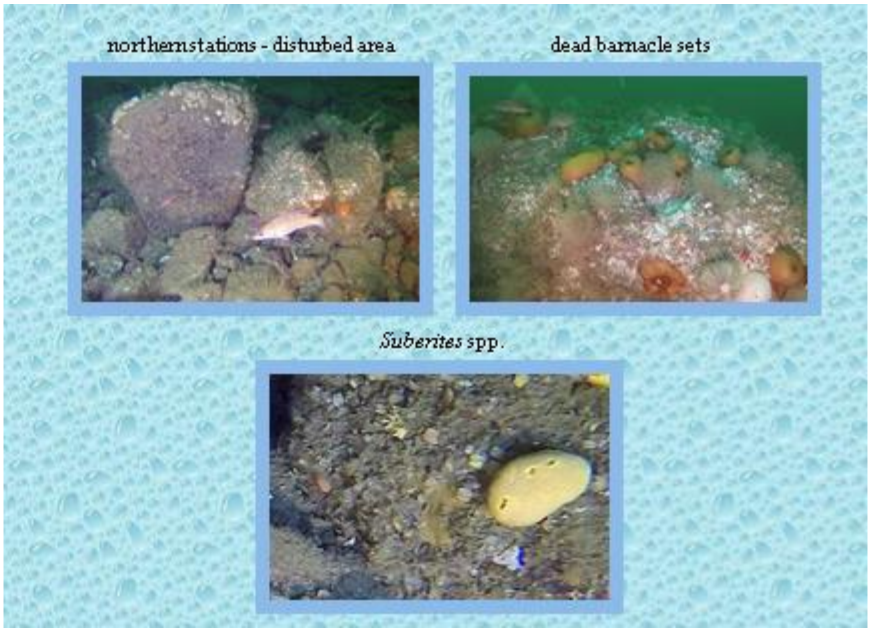
- pre-diversion was only abundant at northern reference sites
- was heavily overgrown by *Membranipora* in 2000
- population crashed in 2001
  - does not appear related to outfall
  - decline related to physical disturbance?
  - appeared at T1-3 in 2010 and 2011
  - only a few at T7-2 in 2014 and also at T12-1 in 2017

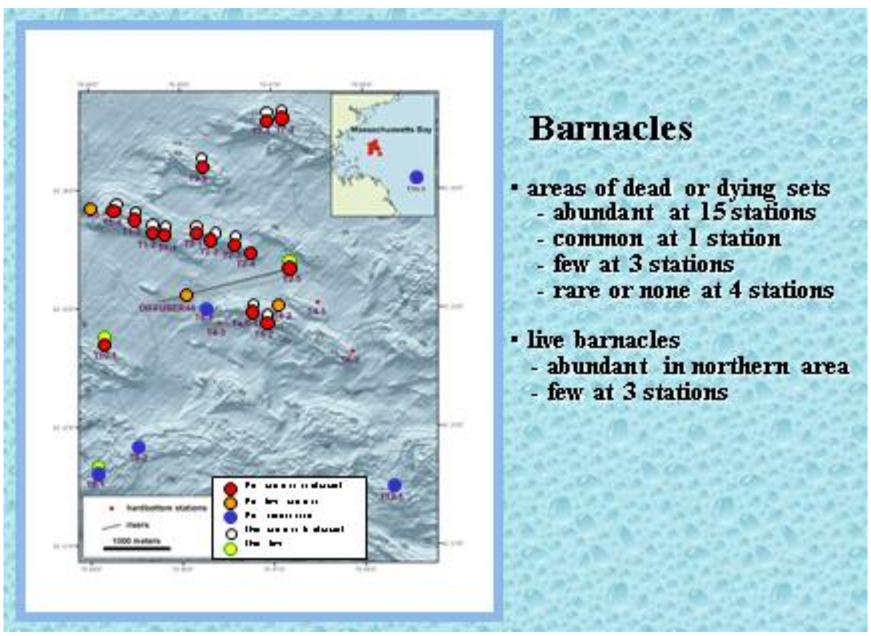

Agarum cribrosum

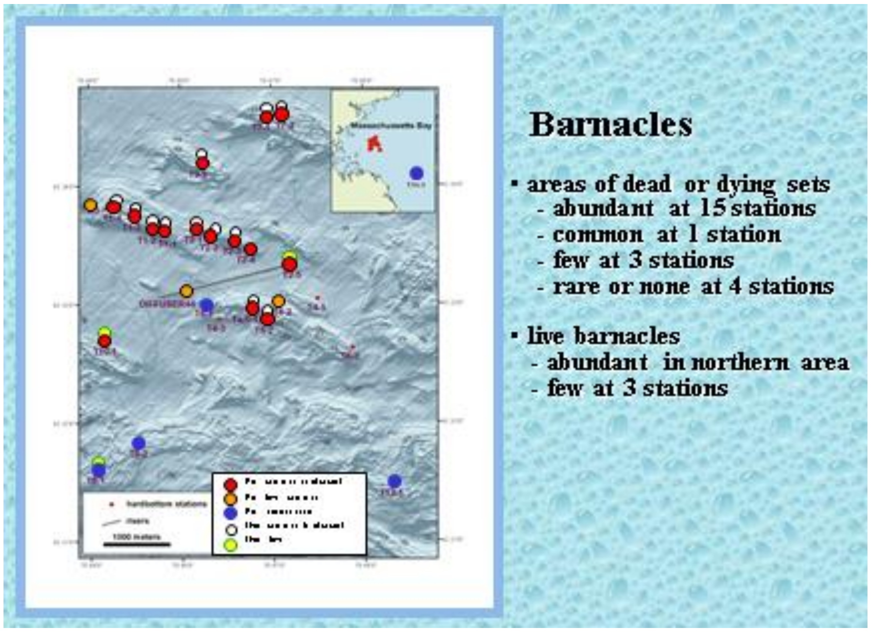

T7-1
1996
1997
1998
2000
2001
2003
2005
2007
2009
2011
2014
2017

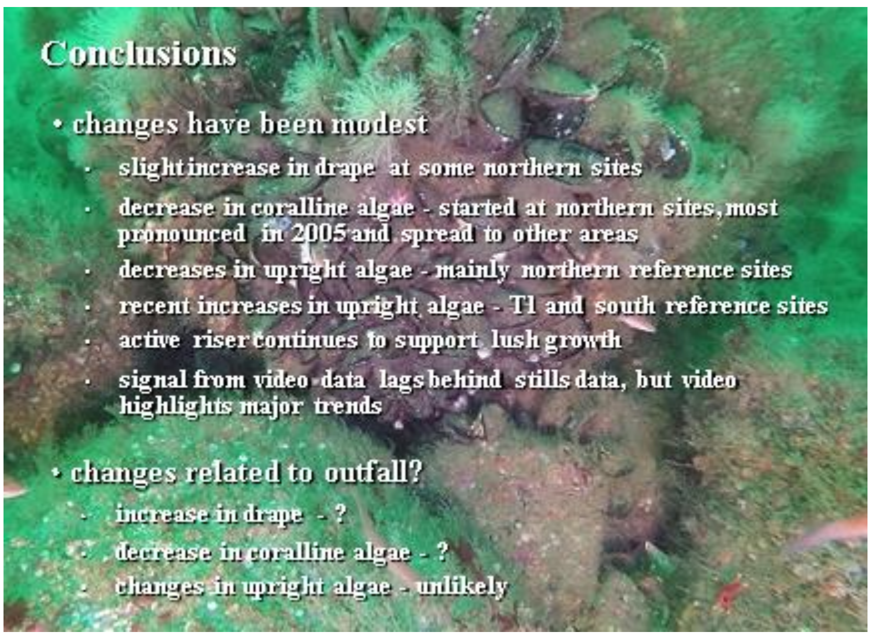

T1-3
1996
1997
1998
2000
2001
2003
2005
2007
2009
2011
2014
2017


T8-1
1995
1997
1998
2000
2001
2003
2005
2007
2009
2011
2014
2017

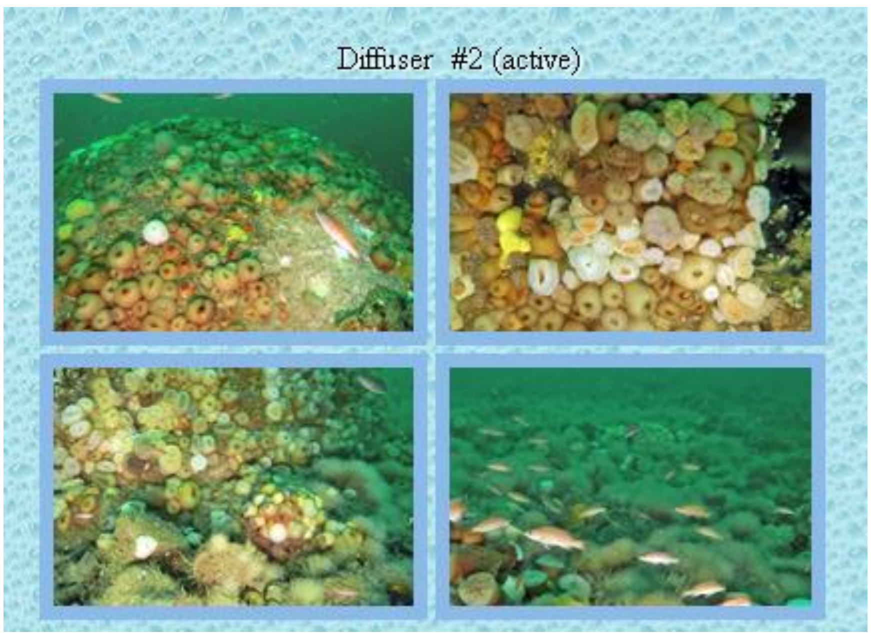

northernstations - disturbed area
dead barnacle sets
*Suberites* spp.


Massachusetts Bay
DIFFUSERS
Barnacles
▪ areas of dead or dying sets
- abundant at 15 stations
- common at 1 station
- few at 3 stations
- rare or none at 4 stations
▪ live barnacles
- abundant in northern area
- few at 3 stations


Barnacles
▪ areas of dead or dying sets
- abundant at 15 stations
- common at 1 station
- few at 3 stations
- rare or none at 4 stations
▪ live barnacles
- abundant in northern area
- few at 3 stations


Conclusions
• changes have been modest
· slight increase in drape at some northern sites
· decrease in coralline algae - started at northern sites, most pronounced in 2005 and spread to other areas
· decreases in upright algae - mainly northern reference sites
· recent increases in upright algae - T1 and south reference sites
· active riser continues to support lush growth
· signal from video data lags behind stills data, but video highlights major trends
• changes related to outfall?
· increase in drape - ?
· decrease in coralline algae - ?
· changes in upright algae - unlikely


Diffuser #44 (inactive)


Diffuser #2 (active)

# Appendix B Summary of Data Recorded from Video Footage Taken On the 2017 Hard-Bottom Survey

| **Station** | **T1-1** | **T1-2** | **T1-3** | **T1-4** | **T1-5** | **T2-1** | **T2-2** | **T2-3** | **T2-4** | **T4/6-1** | **T4-2** | **T6-1** | **T6-2** | **T7-1** | **T7-2** | **T9-1** | **T10-1** | **T8-1** | **T8-2** | **T12-1** | **T11-1** | **T2-5** | **T2-5** | **D#44** | **D#44** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minutes | 24 | 22 | 23 | 22 | 21 | 20 | 22 | 20 | 16 | 21 | 21 | 20 | 21 | 21 | 19 | 19 | 22 | 18 | 22 | 20 | 21 | 24 | | 21 | | 480 |
| Begin depth (m) | 27.5 | 23.2 | 22.3 | 23.8 | 29.3 | 25.9 | 29.9 | 24.4 | 25.7 | 23.2 | 26.8 | 32.9 | 29.9 | 25.3 | 24.7 | 21.6 | 20.1 | 19.8 | 25.6 | 19.5 | 32.3 | 31.7 | | 33.8 | | |
| End depth (m) | 25.6 | 25.9 | 21 | 22.9 | 29.6 | 27.1 | 27.1 | 23.2 | 29.6 | 22.5 | 25.6 | 32.9 | 29.3 | 24.1 | 23.2 | 20.7 | 19.8 | 19.5 | 24.4 | 20.1 | 32 | 26.5 | | 29.3 | | |
| Substrate[1] | mix | b+c | b+c | mix | mix | mix | cp+b | b+c | mix | b+c | cpav-ob | cpav | mix | b+c | b+c | b+c | b | c+ob | mix | c+b | mix | d | rr | d | rr | |
| Drape[2] | m | m-mh | m-mh | lm | lm | lm-m | m-mh | m | m-mh | lm-m | m | mh | lm-m | lm-m | m-mh | lm-m | mh-h | m-mh | l-lm | lm-m | m-mh | l | mh | h | h | |
| Relief[3] | L-M | M-MH | MH | L-LM | L_LM | LM_M | L-M | LM-MH | LM-M | M-MH | L-LM | L | LM-M | M-MH | M-MH | M-MH | MH-H | LM-M | L-LM | LM-M | LM-M | H | LM | H | LM | |
| Suspended matter[4] | h | | | | | | | | | h | h | h | h | | | h | vh | h | h | | | h | | vh | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Coralline algae | f | r | c | c-a | c | f | r | f-c | r | c | f | r | r-f | c | c | f-c | | f-c | c-a | c-a | f | | | | | |
| *Ptilota serrata* | | | c | | | | r | | | | | | | f | f | | | | | f-a* | | | | | | |
| Hydroids | f-c | c | c-a | f-c | f-c | c | f-c | c | f-c | c | f | f-c | f-c | c-a | c | f-c | f | f-c | f-c | r-a | f-c | r | a | a | a | |
| Spirorbids/barnacles | f-c | c | c | c-a | f | | c | | r | a | c | r-f | | c | | c-a | | | f | f | f | a | r | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Palmaria palmata* | r-f | c | c-a | r-f | | r-f | r | f-c | r | f | | | | f-c | c-a | r-f | f | f-c | f-c | f-a | | | | | | |
| *Agarum cribosum* | | | | | | | | | | | | | | | r | | | | | r | | | | | | |
| general sponge | | | | | | | 1 | 7 | 4 | 4 | 1 | | | | | 3 | 1 | 4 | | | 2 | 3 | | 3 | | 33 |
| *Polymastia* sp. A | f-c | c | f | | r | c | c-a | c | c | f-c | r | r | f-c | f | c | f-c | c | f | f | | f | | | c | | |
| *Polymastia* sp. B | | | | 1 | | | | | | | | | | | | | | | | | | | | | | 1 |
| *Haliclona oculata* | | | | | | | | | | | | | | | | | | | | | 1 | | | | 3 | 4 |
| *Suberites* spp. | | | | | | | | | | | | | | | | | | | | | c | | | | | |
| white divided sponge | | | | | | | r-c* | | | | | | | | | | | | | | c | | | | | |
| *Haliclona* spp. (encrusting) | | | | | | 2 | 7 | 2 | 2 | | 3 | | | | | | | 1 | | | | | | | | 17 |
| thick cream sponge with projections | | | | | | | | | | | | | | | | | | | | | c | | | | | |
| yellowish-cream encrusting sponge | | | | | | | | | | | | | | | | | | | | | c | | | | | |
| *Obelia geniculata* | | | | | | | | | | | | | | | r | | | | | | | | | | | |
| general anemone | | | | | | | | | | | | | | | | | | | | | 3 | | | | | 3 |
| *Metridium senile* | | | | | | | | | | | | | | | r | c* | | | | | | a | c | c | r | |
| *Urticina felina* | 1 | 3 | 3 | | | 5 | 5 | 3 | 3 | 5 | | | 4 | 4 | 2 | 3 | 2 | 2 | | | 4 | | 2 | 5 | | 56 |
| *Cerianthus borealis* | | | | | | | | | 6 | | 6 | 1 | | | | | | | | | 1 | | | | | 14 |
| *Gersemia rubiformis* | | | | | | | | | | | | | | | | | r | | | | | | | | | |
| *Tubularia* sp. | | | r-c* | | | | r-c* | c* | | r | | | | | c* | c* | | | | r | | c | a | a | f | |
| gastropod | | | | | | | | | | | 1 | | | | | | | | | | | | | | | 1 |
| *Tonicella marmorea* | | | | | | | | | | | | | 1 | | | | | | | | | | | | | 1 |

| **Station** | **T1-1** | **T1-2** | **T1-3** | **T1-4** | **T1-5** | **T2-1** | **T2-2** | **T2-3** | **T2-4** | **T4/6-1** | **T4-2** | **T6-1** | **T6-2** | **T7-1** | **T7-2** | **T9-1** | **T10-1** | **T8-1** | **T8-2** | **T12-1** | **T11-1** | **T2-5** | **T2-5** | **D#44** | **D#44** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Crepidula plana* | | | | | | | | | c* | | f | | f | | | | f | | | | f | | | | | |
| *Buccinum undatum* | | | | | | | | | | | | 1 | | 4 | | | | 1 | | | 1 | | | | | 7 |
| *Neptunea decemcostata* | | | | | | | | | | | 1 | | | | | | | | | | | | | | | 1 |
| *Modiolus* | c | c-a | a | f-c | r-f | c-a | a | a | c | c-a | r-c | r | c | f | f-c | a | c | f-c | f-c | f-c | a | | | | | |
| *Mytilus edulis* | r | f | a | | | | r-a* | c | | f | r | | | | f-c | f | a | r | | | f | c | | | | |
| *Placopecten magellanicus* | | | | | | | | | | | 12 | 11 | | | | | 1 | 1 | | | | | 1 | | 8 | 34 |
| *Balanus* sp. | a | a | a | c-a | | c-a | c-a | a | | a | | | c | c | a | c-a | f | f | | | r | f | | | | |
| *Homarus americanus* | 1 | 5 | 2 | 3 | | 2 | 1 | 2 | 2 | 3 | 1 | 1 | | 4 | 1 | 4 | 6 | 3 | 1 | 1 | | | | | | 43 |
| *Cancer* spp. | 2 | 4 | 1 | | 5 | 4 | 4 | 3 | | 4 | 2 | 2 | 4 | 1 | | 3 | 2 | 4 | 1 | | | 1 | | | | 47 |
| hermit crab | | | | | | | | | | | 1 | | | | | | | | | | | | | | | 1 |
| *Strongylocentrotus droebachiensis* | | | f-c | | | c | | | | f-c | | | | f | | f | | | r | r | | | | f | r | |
| small white starfish | c-a | c | c | f | c | c | f | f | | c | a | c | f | f | r | f | f | f | c | f-c | c | r | r | r | r | |
| *Asterias vulgaris* | c-a | c | f-c | f | f-c | c | c | f-c* | r-c* | f-c | f-c | c | f-c | f | f | f | r | r | f | r | | r | r | r | r | |
| *Henricia sanguinolenta* | c-a | a | c | f-c* | f-c | c-a | c | c | f-c* | a | c | c | c | c | c | c-a | c | c | c | f-c | c | | r | c | c | |
| *Psolus fabricii* | r | | | r | f | | r | r | | r | r | r | r | | | r | r | r-c* | r | r | | | | f | r | |
| *Botrylloides violaceus* | 3 | 8 | 25 | | | | 4 | 12 | 3 | 6 | 5 | | 2 | | 1 | | 16 | 6 | 2 | 4 | 31 | | | | | 128 |
| *Aplidium/Didemnum* | f | f | f | f | f | r | f | c | f | f | f-c | c | f | | | f | c | f-c | c | f-c | f | | | | | |
| *Dendrodoa carnea* | | | | r | r | | r | | | | | r | r | r | f | | | | | | f | | | | | |
| *Halocynthia pyriformis* | r | | | | | | r-a* | f | | | | | r | r | r | r | | | r | | r | | | f | r | |
| *Membranipora* sp. | | r | | | | | | | | | | | | | | | r | | r | | | | | | | |
| *Myxicola infundibulum* | | | | | | r | r | | | r | | r | | | f | r | | | | | f | | | | | |
| *Terebratulina septentrionalis* | r | | | | | | r-a* | c-a* | | r | r | | r | | f | c* | r | r | | r | c | | | | | |
| general fish | | | | | | | | | | 4 | 1 | | | | >20 | | 4 | 2 | | | 1 | | | 1 | | 13 |
| *Tautogolabrus adspersus* | f-c | c-a | a | f-c | r-f | f-c | f-c | c-a | f-c* | f-c | r-f | r | r-f | c | c-a | f-a | f-c | c | f | c | r | a | a | a | c | |
| *Myoxocephalus* spp. | 2 | 5 | 1 | 4 | 6 | 3 | 7 | 1 | | 2 | 3 | 6 | 9 | | 1 | 1 | | 5 | 2 | 1 | 1 | | | | | 60 |
| *Macrozoarces americanus* | | | | | | | | | | | | 1 | | 1 | | | | | | | | | | | | 2 |
| *Anarhichas lupus* | | | | | | | 1 | | | | | | | | | | | | | | 1 | | | | | 2 |
| *Hemitripterus americanus* | | | | | | | | | | | | | | | | | | | | 1 | | | | | | 1 |

| Station | T1-1 | T1-2 | T1-3 | T1-4 | T1-5 | T2-1 | T2-2 | T2-3 | T2-4 | T4/6-1 | T4-2 | T6-1 | T6-2 | T7-1 | T7-2 | T9-1 | T10-1 | T8-1 | T8-2 | T12-1 | T11-1 | T2-5 | T2-5 | D#44 | D#44 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pseudopleuronectes americanus* | | | | 4 | 8 | | | 1 | | 5 | 2 | 2 | 2 | | 1 | 1 | 1 | 5 | 2 | 1 | | 1 | 3 | | | 39 |
| *Sebastes fasciatus* | | | | | | | | | | | | | | | | | | | | | | | 4 | | | 4 |
| *Gadus morhua* | | | 6 | | | | 1 | | | | | | | 2 | | | | | | | | | | | 1 | 10 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| whelk egg case | | | 2 | | 2 | | | | | | 1 | | | | | 1 | | | | | | | | | | 6 |
| nudibranch egg mass | 2 | | | | | | | | | | | | | | 1 | | | | | 3 | | | | | | 6 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ex barnacles | a | a | a | a | f | a | a | a | a* | a | f | | a | a | a | a | a | f | | | | a | | c | | |

[1] b=boulder, ob=occasional boulders, c=cobble, cp=cobble pavement, d=diffuser head, r=riprap.
[2] l=light; lm=moderately light; m=moderate; mh=moderately heavy; h=heavy.
[3] L=low; LM=moderately low; M=moderate; MH=moderately high; H=high.
[4] h=high, vh=very high.
Values a=abundant, c=common, f= few, r = rare.

# Appendix C Taxa Observed During the 2017 Nearfield Hard-Bottom Video Survey

| Name | Common name | Name | Common name |
|---|---|---|---|
| **Algae** | | | |
| Coralline algae | pink encrusting algae | *Homarus americanus* | American lobster |
| *Ptilota serrata* | filamentous red algae | hermit crab | |
| *Palmaria palmata* | dulse | | |
| *Agarum cribosum* | shotgun kelp | **Echinoderms** | |
| | | *Strongylocentrotus droebachiensis* | green sea urchin |
| **Invertebrates** | | small white starfish | juvenile *Asterias* |
| **Sponges** | | *Asterias vulgaris* | northern sea star |
| general sponge | | *Henricia sanguinolenta* | blood star |
| *Haliclona oculata* | finger sponge | *Psolus fabricii* | scarlet holothurian |
| *Haliclona* spp. (encrusting) | sponge | | |
| *Polymastia* sp. A | encrust yellow sponge | **Tunicates** | |
| *Polymastia* sp. B | soft substrate sponge | *Aplidium/Didemnum* spp. | cream encrust tunicate |
| *Suberites* spp. | fig sponge | *Botrylloides violaceus* | Pacific tunicate |
| cream sponge/projections | sponge | *Dendrodoa carnea* | drop-of-blood |
| yellowish-cream encrusting | sponge | *Halocynthia pyriformis* | sea peach tunicate |
| white divided sponge | sponge on brachiopod | | |
| | | **Miscellaneous** | |
| **Coelenterates** | | *Membranipora* sp. | lacy bryozoan |
| Hydroids | | *Myxicola infundibulum* | slime worm |
| *Obelia geniculata* | zig-zag hydroid | Spirorbids/barnacles | |
| *Tubularia* sp. | hydroid | *Terebratulina septentrionalis* | northern lamp shell |
| general anemone | | | |
| *Metridium senile* | frilly anemone | **Fishes** | |
| *Urticina felina* | northern red anemone | general fish | |
| *Cerianthus borealis* | northern cerianthid | *Anarhichas lupus* | wolffish |
| *Gersemia rubiformis* | red soft coral | *Gadus morhua* | Atlantic cod |
| | | *Hemitripterus americanus* | ocean pout |
| **Molluscs** | | *Macrozoarces americanus* | sculpin |
| gastropod | | *Myoxocephalus* spp. | rock gunnel |
| *Crepidula plana* | flat slipper limpet | *Pseudopleuronectes americanus* | winter flounder |
| *Tonicella marmorea* | chiton | *Sebastes fasciatus* | rosefish |
| *Buccinum undatum* | waved whelk | *Tautogolabrus adspersus* | cunner |
| *Neptunea decemcostata* | | | |
| *Modiolus* | horse mussel | **Other** | |
| *Mytilus edulis* | blue mussel | | |
| *Placopecten magellanicus* | sea scallop | egg case | |
| | | nudibranch egg case (frilly white) | |
| **Crustaceans** | | ex barnacles | |
| *Balanus* sp. | barnacle | | |
| *Cancer* spp. | Jonah or rock crab | | |

# Appendix D 2017 Hard-Bottom Still Images

**Appendix D. 2017 hard-bottom still images**

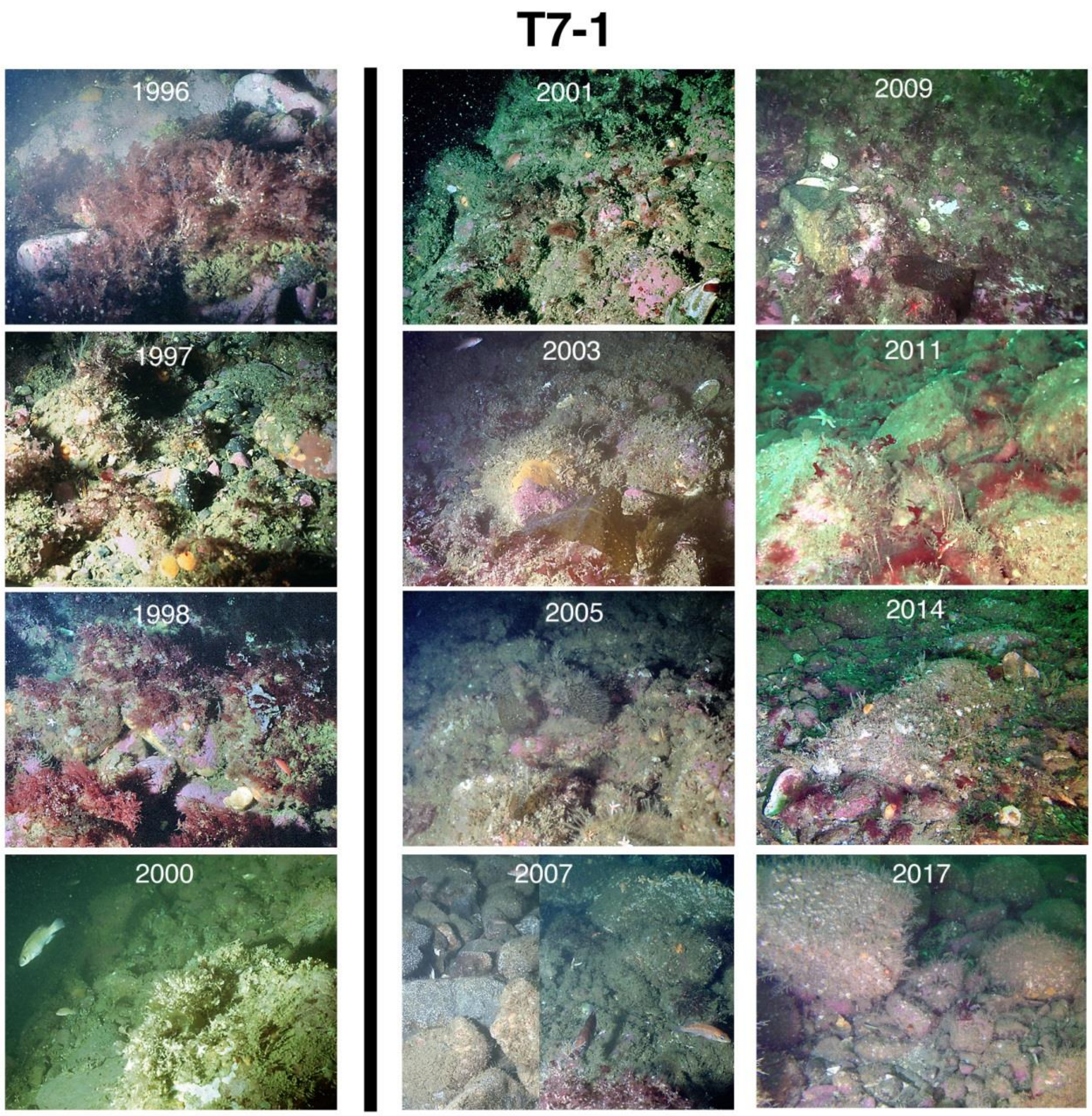



**Plate 1. Representative images through time at T7-1 one of the northern reference sites. The four images on the left (1996, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by upright algae during this period. The eight images on the right show representative images from the post diversion period. The number of upright algae and the percent cover of coralline algae generally decreased over time. Some of these changes may reflect physical disturbance of the seafloor by tankers anchoring at the northern reference sites. One such disturbed area can be seen in the left half of 2007 image, where overturned boulders are characterized by little drape, little coralline algae cover, and few encrusting organisms.**

**Appendix D. 2017 hard-bottom still images (continued)**

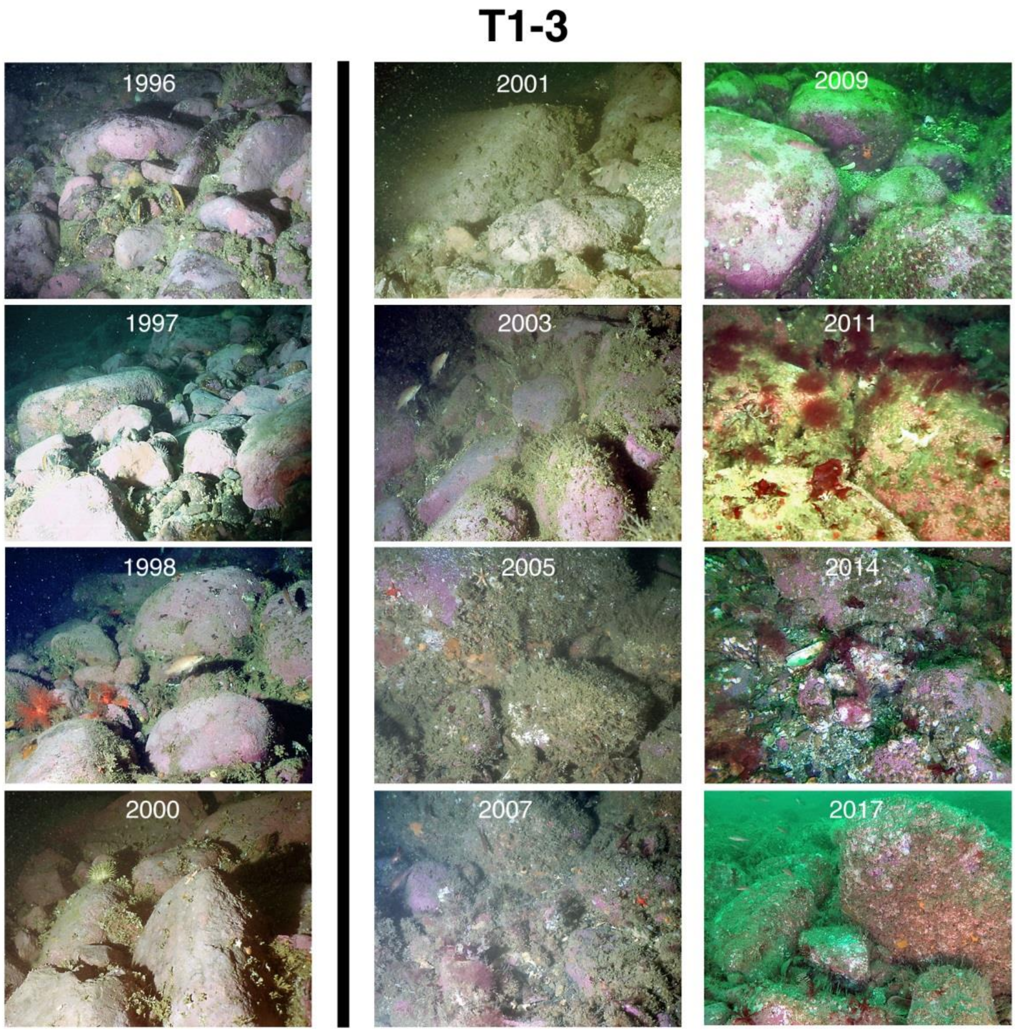



**Plate 2. Representative images through time at T1-3 a drumlin top site north of the outfall. The four images on the left (1996, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was totally dominated by coralline algae and the rocks had very little drape during this period. The eight images on the right show representative images from the post diversion period. The percent cover of coralline algae generally decreased over time and the amount of drape on the rock surfaces increased. Additionally, upright algae started appearing at this site since 2011.**

**Appendix D. 2017 hard-bottom still images (continued)**

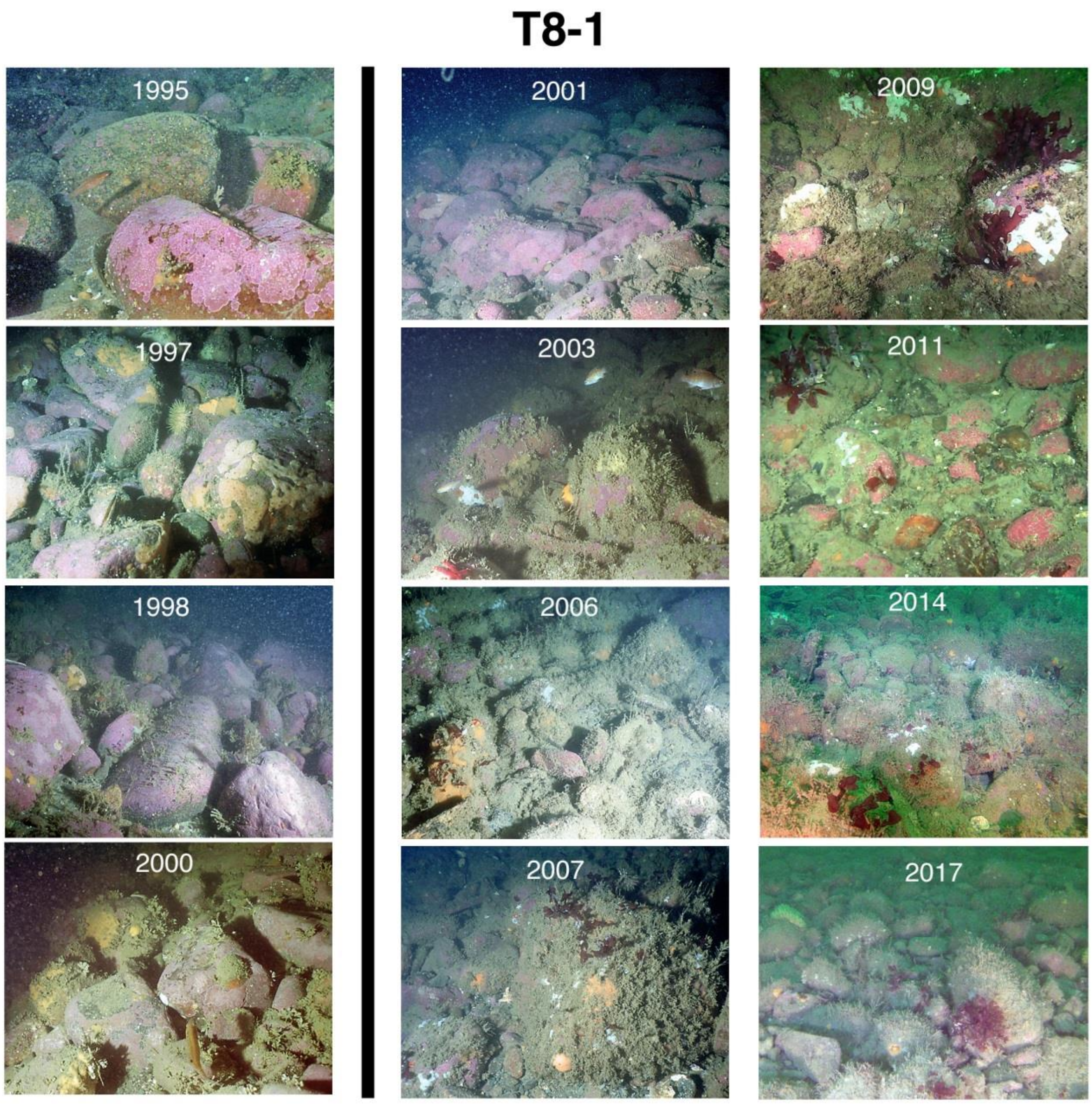



**Plate 3. Representative images through time at T8-1 one of the southern reference sites. The four images on the left (1995, 1997, 1998 and 2000) show this site during the pre-diversion years. The benthic community was dominated by coralline algae during this period. The eight images on the right show representative images from the post diversion period. The percent cover of coralline algae generally decreased over time and more drape can be seen on the rock surfaces. Additionally, numerous colonies of dulse (*Palmaria palmata*) have been seen at this site since 2007.**

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000
www.mwra.com